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Comprehensive Drainage Study of the Upper Reach of College Branch in Fayetteville, Arkansas

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COMPREHENSIVE DRAINAGE STUDY OF THE

UPPER REACH OF COLLEGE BRANCH IN FAYETTEVILLE, ARKANSAS

COMPREHENSIVE DRAINAGE STUDY OF THE UPPER REACH OF COLLEGE BRANCH IN FAYETTEVILLE, ARKANSAS

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of the requirements for the degree of
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ABSTRACT

College Branch is a stream with headwaters located on the University of Arkansas campus. The stream flows through much of the west side of campus, gaining discharge and enlarging its channel as it meanders to the south. College Branch has experienced erosion and flooding issues in recent years due to increased urbanization of its watershed and increased runoff volume.

The purpose of this project was to develop a comprehensive drainage study of College Branch on the University of Arkansas campus. Storm runoff and flood flow patterns were evaluated in order to understand the hydraulics and hydrology of the watershed and identify problem areas associated with excess runoff during storm events, including flooding and stream bank erosion. In addition to an evaluation of the present watershed, the study included proposed designs for changes to the stream channel, its banks, and areas surrounding the stream and in its watershed that could alleviate the amount of runoff during storms, stabilize the banks of the stream, and protect College Branch and its watershed from future destabilization.

The availability of a comprehensive drainage study for the University of Arkansas reach of College Branch allows the university to make more-informed decisions concerning the current state of College Branch and the future development of its watershed.

This thesis is approved for recommendation
to the Graduate Council.

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1. INTRODUCTION

1.1 Research Purpose

The purpose of this project is to develop a comprehensive drainage study of College Branch on the University of Arkansas campus. This study will include hydraulic and hydrologic evaluations of the stream and its watershed. In addition to a study of the present watershed, the study will incorporate proposed changes to the stream channel, its banks, and areas surrounding the stream and in its watershed. The watershed and the stream will be modeled and the runoff potential for various storm events will be evaluated. Using the runoff values calculated, stream and watershed designs will be created to capture excess runoff and return the watershed to a stable condition. Variations of design will be created using runoff data, morphological data, and real time data collected from the available USGS gage station. Each design variation will be analyzed and its stabilization performance evaluated.

The drainage study for the University of Arkansas reach of College Branch will allow the university to make more-informed decisions concerning development and storm drainage structures. The study will also provide possibilities for improvements to the drainage system presently and in the future.

1.2 Site Description

College Branch is a stream that begins on the University of Arkansas campus in Fayetteville, Arkansas. College Branch is also referred to as Mullins Creek and is a tributary to Town Branch, a larger creek that flows eastward through the southern area of Fayetteville. Town Branch flows into the West Fork of the White River, which was dammed in the 1960's to form Beaver Lake, the major source of potable water for Northwest Arkansas (Bolyard, De Lanois, and Green, 2010). Figure 1 displays a regional map of Northwest Arkansas with the streams labeled.

College Branch has become a subject of increasing concern for University of Arkansas Facilities Management (FAMA) over the years. Its flooding issues and erosion problems have become a topic of study for classes, graduate work, and the University of Arkansas Community Development Center (UACDC). The growth of these problems and mounting concern for the issues have led to the need for a comprehensive study of College Branch and its watershed in order to better understand the effect of urbanization on the stream, the need for improvements to the stream and surrounding areas, and the future actions of the University of Arkansas needed to develop university property and maintain the stream's hydrologic and ecologic functions.

An aerial map of College Branch Watershed is given (Figure 2). The watershed delineation was obtained from the Natural Resource Conservation Service (NRCS) Watershed Boundary Dataset (WBD) (NRCS, 2010). The College Branch Watershed is a 12-digit Hydrologic Unit Code (HUC) subwatershed of the Town Branch-West Fork-White River Watershed and is about 800 acres in area. The watershed area for this project will only include the areas north of U.S. Highway 62 that contribute flow to the section of College Branch on the University of Arkansas campus. This portion of the watershed is approximately 490 acres.

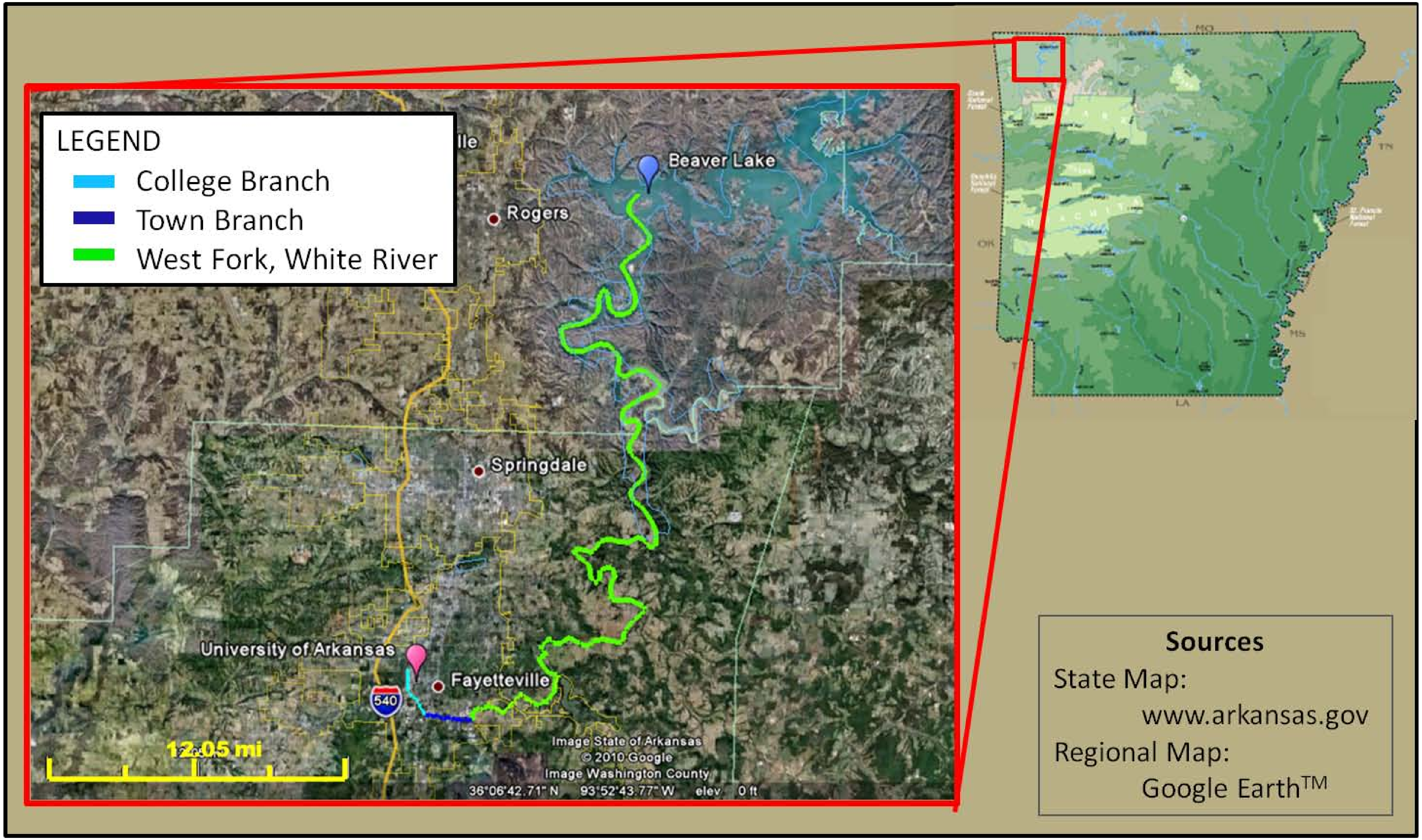

Figure 1. Regional Map of Northwest Arkansas displaying the streams of interest

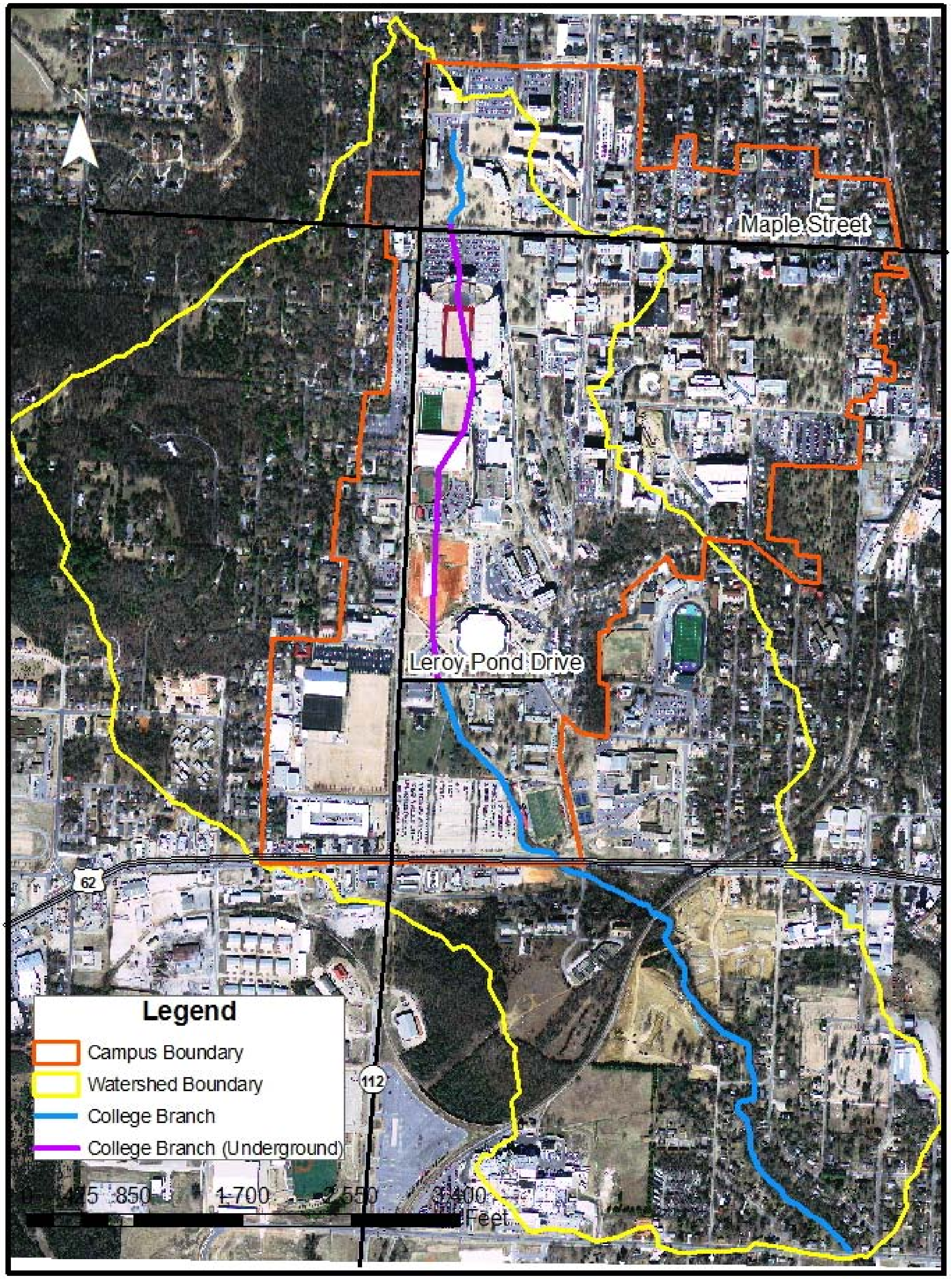

Figure 2. Aerial View of College Branch Watershed

The headwaters of College Branch are located on Maple Hill, an area in the northwestern corner of campus. The headwaters consist of flow from various storm drainage pipes that release water captured from stormwater culverts and other drainage components (Figure 3a). The converged flow from these pipes then courses downhill, capturing flow from other storm drains along the way until reaching Maple Street (Figure 3b). Boulders have been placed in and along the stream in an attempt to guide its flow. The segment of stream upstream from Maple Street has little to no flow during dry periods. The segment of College Branch just north of Maple Street is pictured in Figure 3c.

At Maple Street, the flow of College Branch is directed into a metal-grated storm drain that is situated level with the ground. The flow falls through this grate for approximately 10 feet into a large concrete lined box which collects flow from the stream and multiple storm drainage pipes. After the flows converge in this box, the stream continues southward underneath Maple Street. The storm drain at Maple Street is pictured in Figure 3d.

Figure 3a.
Headwaters of College Branch

Figure 3b.
Storm drain that contributes to College Branch north of Maple Street

Figure 3c.
College Branch just north of Maple Street

Figure 3d.
Storm drain that captures College Branch just north of Maple Street

Donald W. Reynolds Razorback Stadium is located directly south of Maple Street. The football stadium, formally known as Razorback Stadium, was constructed in 1938 (Leflar, 1972), directly above the existing stream. Prior to this construction, the stream was completely above ground and meandered through fields, as shown in an aerial photograph taken in 1926. This photograph is given in Appendix A. The stadium construction included the channelization of College Branch into a series of underground pipes. As the university developed, the stream was further channelized underground to allow for surface structures such as parking lots, roads, and buildings to be constructed. During its flow underground, College Branch collects flow from multiple storm drains, increasing its size and volumetric flow rate.

Just south of Leroy Pond Drive, College Branch resurfaces through an outlet structure comprising of three concrete boxes (each approximately 7 feet by 3 feet) with metal grates. The flow drops approximately 1 foot as the stream leaves the culvert and enters a channel. The outlet at Leroy Pond Drive is pictured in Figure 4a.

From Leroy Pond Drive, the stream flows through The Gardens area of campus, which is a grassed area commonly used for picnics and tailgating with gazebos and a pavilion. The stream banks in this area are eroded and void of much riparian material. A past stream rehabilitation attempt included placement of boulders along the stream banks in this section of stream (Figure 4b). Some of the boulders remain along the banks, while others have fallen in and cause flow diversion around them, leading to stream bank erosion alongside and immediately downstream of these in-stream boulders (Figure 4c). As the stream flows toward Lady Razorback Road, the riparian area around the stream becomes almost nonexistent, leaving the stream banks to erode and be subject to full sunlight. This segment of the stream is pictured in Figure 4d.

Figure 4a.
Stream leaving outlet at Leroy Pond Drive

Figure 4b.
Boulders from past rehabilitation project
(looking downstream)

Figure 4c.
Misplaced boulder causing flow diversion and
erosion

Figure 4d.
Stream just east of the Gardens area
(looking downstream)

In the section of College Branch between Leroy Pond Drive and Lady Razorback Road, two footbridges cross the stream and three storm drainage pipes direct effluent into it. One drainage pipe captures runoff from Lot 56B, which is located to the west of the stream just south of Leroy Pond Drive. Another directs runoff from The Gardens area, and the third captures flow from in and around Bogle Field, the Razorback softball facility. The locations of these drainage pipes are pictured in an aerial map of the Gardens area of campus (Figure 5).

Figure 5.
Aerial view of College Branch flowing through the Gardens area of campus

At Lady Razorback Road, the stream flows under a bridge with a pier separating the stream flow into branches. One branch carries most of the stream flow, while the other flows intermittently, at other times holding stagnant water. The stream as it flows under the bridge is pictured in Figure 6a.

As the stream exits this structure, it enters a dense riparian area with in-stream trees and other plants. In this section of stream, College Branch flows just to the east of Lot 56, a large parking lot in the southernmost part of the university campus. Two large storm structures drain into the stream. Both capture flow from Lot 56, as well as other areas on the west section of campus. Some city runoff is also captured and directed to these drainage structures. The structures consist of large concrete pipes that direct flow through metal grates before the flow enters College Branch. At the time of this study, a collection of debris was present on the inside of these pipes. One of the storm drains flowing into College Branch at Lot 56 is pictured in Figure 6b.

Near U.S. Highway 62 (Martin Luther King, Jr. Boulevard), heavy erosion occurs as there is a sharp bend in the stream as it turns east (Figure 6c). Downstream of the sharp bend, rip rap has been placed along the south bank to protect it from erosion. The vegetation becomes very dense along the banks in the most southern segment of the stream on campus, just upstream of the bridge at U.S. Highway 62 (Figure 6d). The stream flows under the highway and continues to flow in a southeastern direction.

Figure 6a.
Stream under the Lady Razorback Road Bridge

Figure 6b.
Storm drain flowing into College Branch

Figure 6c.
Sharp turn in College Branch near Hwy. 62

Figure 6d.
Just upstream of stream outlet from campus

United States Geological Survey (USGS) gage station 07048480 is located at the Highway 62 Bridge where the stream leaves campus (USGS, 2010). This gage station collects data at 5-minute intervals on stream flow, including gage height, discharge, and precipitation.

There exist a variety of problems with College Branch and its watershed. The watershed is a highly urbanized area. This high level of impervious surface has led to large amounts of runoff during storm events, which flows toward the stream and is eventually added to the flow of the creek. Storm drains located within the watershed collected runoff and direct it through underground pipes toward the stream, where it is also added to the overall flow of the creek. As the watershed becomes more developed, the problem of increased flow in the stream worsens.

The stream banks of College Branch have been restricted by pipes and structures in order to control its location and to protect structures on campus. The increased amount of runoff and restrictions on the stream has led to channel incision and bank erosion, as pictured previously (see Figures 4c, 4d, and 6c). Erosion causes sediment to enter the stream, which can decrease water quality and impair the ecology and natural habitat within the channel and along the banks.

Various structures restrict and cause changes in stream flow. These include the aforementioned bridges and culverts as well as various pipes that cross the stream. These pipes cross the stream and divert flow, causing problems including channel incision and ponding just upstream of the obstructions.

Though College Branch is a small creek, its problems could be carried downstream to larger water bodies. For example, College Branch has experienced heavy erosion while flowing through the University of Arkansas campus. This erosion leads to suspended sediment in the stream, which is a cause of turbidity in the water. According to the Arkansas Department of Environmental Quality 303 (d) list for impaired waters, the West Fork of the White River has experienced impaired water quality due to high siltation and turbidity values (ADEQ, 2000). Flow from College Branch could contribute to the turbidity problems in the White River. Also, increased peak flows and suspended sediments could cause channel incision and erosion downstream of campus, which would create problems for downstream landowners.

2. LITERATURE REVIEW

2.1 Urban Drainage Studies

Drainage studies have been performed for many areas around the country and world for the purpose of coordinating development with stormwater drainage systems and allowing for mitigation of urban growth. For example, a Surface Water Management Plan was created for Polk County, Florida in 1987 in order to prevent drainage problems and "mitigate growth impacts" (Shea et al., 1993). Previous to the study, problems with drainage were amended on a "case-by-case" basis due to lack of a comprehensive study of drainage patterns. Similarly, the city of North Little Rock, Arkansas, contracted an engineering firm to perform a stormwater management analysis and provide feedback for drainage and structure improvements (Carter-Burgess, 1998). This analysis included identification of problem areas, hydrologic and hydraulic modeling, and designs for drainage improvement and expansion. Aerial drawings of each drainage basin in North Little Rock were provided with existing and proposed structures and channels. A prioritized list of suggestions concluded their study.

Drainage studies have also been performed for other university campuses. A management plan was conducted for Strawberry Creek on the University of California at Berkeley campus (Charbonneau, 1987). This plan, submitted as a master's thesis for city planning, included site characterization for the stream and the watershed, an environmental assessment, and strategies for creek stabilization and stormwater management.

2.2 Urbanization

Many studies have found that urbanization is a direct cause of problems regarding storm drainage and stream flow. The five major effects of urbanization, as defined by Shaw (1994), are (1) a higher percentage of rainfall becomes surface runoff, (2) decreased lag time between rainfall and runoff (3) increase in peak flows (4) decrease in low flow because of reduced groundwater storage, and (5) water quality degradation. Urban areas can be defined by their large amount of impervious surfaces (Lu and Weng, 2006). These surfaces, which include pavement and roofs, increase in area as urbanization increases through development.

Streams that flow through an urban area face problems due to the urbanization around them. Where rural and natural streams receive stormwater from nonpoint sources such as overland flow, urban streams become a catch-all for stormwater flow from drainage pipes. In this manner, urban streams have become viewed as “drains” in an urban drainage system (Walsh, 2000). Though the function of the stream as a storm drain may be necessary and beneficial to the urban drainage system, the stream and its ecosystem become degraded.

Direct effects on a stream due to urbanization include channel enlargement and flooding. A channel’s depth and width can both be increased due to headwater urbanization (Booth, 1990). This occurs because of an increase in runoff discharge and frequency, which requires a larger channel in which to be carried. Increase in depth, also known as channel incision, is commonly caused by an “excess sediment-transporting capacity” in relation to the amount of bed material transported from upstream (Simon and Rinaldi, 2006). This excess in capacity is also due to the increased discharge during storm events because of urbanization. As erosion occurs in some areas of a stream, sediment is carried until deposition occurs downstream. This “complex cycle” of erosion and deposition occurs as the stream tries to meet the new needs of its watershed (Otten, 1998).

Another problem caused by urbanization is increased pollutant and nutrient loads in the receiving stream. The efficiency, or speed, of the drainage system can affect the level of water quality degradation (Walsh, 2000). Higher pollutant loading during runoff periods can result from a higher efficiency level of stormwater conveyance through the drainage system. Some studies have reported that the quality of urban runoff is like that of raw sewage (Klein, 1979). Pollutants from automobiles, parking lots, and roadways degrade water quality by adding inorganic material such as heavy metals to the stream, as well as organics such as hydrocarbons and phenols (Jiries, Hussein, and Halaseh, 2001). One study defined “chronic” pollutants as those present year-round (Legret and Pagotto, 1999). These include suspended solids, metals (such as zinc and lead), hydrocarbons, and pollution resulting in chemical oxygen demand (COD). The study defined “seasonal” pollutants to be those present in only certain types of year. These include chlorides, sulfates, suspended solids, and heavy metals that result from deicing salt distributed during inclement weather.

Use of fertilizers and pesticides in urban areas can also degrade the stream’s water quality. Fertilizers can increase the level of nitrates and phosphates in runoff, in turn increasing the chances of eutrophication in the stream (Easton and Petrovic, 2003). Eutrophication in aquatic ecosystems can cause loss of species and loss of services provided by that species to the ecosystem (Smith, Tilman, and Nekola, 1999).

2.3 Runoff Analysis

According to the Environmental Protection Agency (EPA), runoff is “that part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface-water” (EPA, 2006). With the increase of runoff volume due to urbanization, it is useful to determine past, current, and future runoff amounts produced by storms in a watershed.

Runoff analysis methods are either statistical or deterministic in nature (Driver and Tasker, 1990). Statistical methods are based on relationships between physical, land use, and climatic characteristics of a watershed. Some models are generally applicable; others, known as regional regression models, are developed for specifical geographical regions or land types. Deterministic methods are based on a specific site's runoff information, usually gathered from a gage station.

There are a variety of widely used statistical methods for runoff and peak flow calculations. Peak flow is the flow rate, or discharge, that occurs at the maximum water surface elevation during a storm event (McCuen, 2005). Peak flow is a common parameter for stormwater analysis and design. The various runoff analysis methods include the NRCS Method and the Rational Method, as well as other statistically-developed methods for the determination of an area's peak flow.

In a runoff analysis, the volumetric flow rate is determined for various storm events. Many municipalities have requirements that define the storm events necessary for design. The City of Fayetteville, Arkansas, requires that detention facilities be designed for the 2, 10, 25, 50, and 100-year storms, and that these facilities limit the post-development flows to pre-development rates (City of Fayetteville, 1995b).

2.3.1 NRCS Method

The Natural Resources Conservation Service (NRCS), formally known as the Soil Conservation Service (SCS), developed a statistical method for peak flow determination based on rainfall, soil type, and land use (McCuen, 2005). This method uses a variable known as Curve Number (CN) that represents the specific hydrologic soil group (HSG), land cover, antecedent moisture condition, and hydrologic condition of an area (NRCS, 1986). The value of CN can range for 0 to 100, with 100 representing a completely impervious area. Defined runoff CN's for urban areas are given in Technical Release No. 55 (TR-55), which is published by the NRCS (NRCS, 1986).

The CN for an area is used to calculate the potential maximum retention, S, of a watershed, as shown in Equation 1.

$$S = \frac{1000}{CN} - 10 \qquad\qquad Equation\ 1$$

The potential maximum retention, in turn, is directly related to the initial abstraction, I_a, as displayed in Equation 2.

$$I_a = 0.2S \qquad\qquad Equation\ 2$$

Knowing the potential maximum retention, initial abstraction, and the 24-hour rainfall depth, P (in inches), the runoff depth, Q (in inches), can be found (Equation 3).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad\qquad Equation\ 3a$$

Inserting Equation 2 into Equation 3a produces Equation 3b, below.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad\qquad Equation\ 3b$$

Equation 3a and 3b calculate runoff in terms of depth. In order to calculate the peak discharge in terms of volumetric flow, the graphical peak discharge method is utilized (McCuen, 2005). In order to calculate peak discharge, the drainage area, A_m (in square miles), and the unit peak discharge, q_{um} (in cfs/mi^2/inch), must be known. Equation 4 displays the calculation for peak discharge.

$$q_p = q_{um} A_m Q \qquad\qquad Equation\ 4$$

The unit peak discharge is found by graphical means, and is dependent on the time of concentration, the initial abstraction to rainfall (I_a/P) ratio, and the NRCS rainfall distribution type for the study area. TR-55 provides unit peak discharge graphs for each type of rainfall distribution. A study areas rainfall distribution type can be determined using a map also given in TR-55 (NRCS, 1986).

The time of concentration (T_c) is the total time of travel (T_t) for a watershed, and is dependent on flow type (NRCS, 1986). Sheet flow is which is defined as "flow over plane surfaces". Time of travel (in hours) for sheet flow (less than 300 feet) can be found using Equation 5, where n represents Manning's unitless roughness coefficient, L represents flow length (in feet), P_2 is the 2-year, 24-hour rainfall (in inches), and S is the slope (in ft/ft).

$$T_t = \frac{0.007(nL)^{0.8}}{(P_2)^{0.5}S^{0.4}} \qquad \textit{Equation } 5$$

After the maximum 300 feet of sheet flow, the flow normally becomes shallow concentrated flow. Velocity for this section of flow can be found using a slope versus velocity graph in TR-55 (NRCS, 1986). Knowing the velocity (V) and length of flow (L), time of travel (T_t) in hours can be found with Equation 6. L should be given in feet and velocity in feet/sec.

$$T_t = \frac{L}{3600V} \qquad \textit{Equation } 6$$

Channel flow is flow located in an open channel. The time of travel can be found with Equation 6, with the velocity (in ft/sec) being determined with Manning's Formula, given in Equation 7. Manning's Formula takes into account the surface roughness, slope (in ft/ft), and the channel geometry. The variable R represents the hydraulic radius, which is the ratio of cross-sectional area to wetted perimeter of the channel. Hydraulic radius is given in feet.

$$V = \frac{1.49}{n}R^{2/3}S^{1/2} \qquad \textit{Equation } 7$$

The overall time of concentration for a watershed is the sum of each flow type's time of travel. Knowing time of concentration, the unit peak discharge is determined and then the peak discharge is found.

2.3.2 Rational Method

The Rational Method is another technique for peak discharge determination. It is dependent upon the drainage area, A, rainfall intensity, i, and a runoff coefficient, C, which is determined by the watershed's land use, hydrologic soil group, and slope (McCuen, 2005). Peak discharge is calculated using Equation 8.

$$q_p = CiA \qquad\qquad Equation\ 8$$

An Intensity-Duration-Frequency (IDF) curve is used to determine the rainfall intensity. An IDF curve relates the intensity of the rainfall in depth per time to the duration of a storm (in minutes or hours) for each storm event's return period.

The Rational Method is considered the simplest rainfall-runoff model (Crobeddu, Bennis, and Rhouzlane, 2007). However, its simplicity also leads to its limitations. The Rational Method is intended for small return periods such as 5 and 10 years and is most accurate when used for areas with low permeability (Telford, 2004). Also, due to the method's assumption that the rainfall intensity is constant throughout the storm, the method is best applicable for watersheds under 200 acres in drainage area (Houghtalen, Akan, and Hwang, 2010).

Even with its limitations, the Rational Method is widely used in design, especially in designing drainage components such as inlets and culverts (McCuen, 2005). Northwest Arkansas municipalities, such as the city of Bentonville, suggest that the Rational Method be the runoff determination method of choice for drainage areas less than 10 acres and an acceptable method for drainage areas up to 100 acres (City of Bentonville, 2008). The City of Fayetteville limits the use of the Rational Method to studies of drainage areas of less than 200 acres (City of Fayetteville, 1995a).

2.3.3 Other Statistical Methods

For geographical areas with sufficient data, regional regression curves are used to most accurately predict peak flows at stream sites. For example, a study in Idaho produced a regional regression equation that determined peak flow for a 10-year event and provided ratios for the 25- and 50-year events (Berenbrock, 2002). The USGS has developed many regional regression models that use relationships between watershed, climate, and flood characteristics of a geographical area to estimate future flows (Thomas, 1993). Three types of regression methods have been used in various studies since 1949. The first, the index-flood procedure, involved developing a dimensionless curve that compared flood discharge to the mean annual flood, and then comparing the mean annual flood to the watershed and climate of the region. The second regression method, known as the ordinary-least-squares regression, estimated the peak discharges for return periods by directly comparing to watershed and climate characteristics. The third type, the generalized-least-squares regression, takes into account the fact that gage stations have varying lengths of record when developing the regression curve for the region.

Reports containing the above regression techniques were evaluated and used to develop flood frequency equations for urban and rural areas in each of the 50 states for the National Flood Frequency (NFF) Program, now known as the National Stream Statistics (NSS) Program (Riggs and Thomas, 1993). Arkansas is divided into two regions; Region A covers the Mississippi River Alluvial Plain (the eastern portion), while Region B includes the higher elevated areas of the state (mainly the western portion and Crowley's Ridge). A map of the regions is given in Figure 7. For each region, a set of equations was developed to determine peak discharge for storm events of 2, 5, 10, 25, 50, and 100 years. Equation sets 9 and 10 display these regional peak plow equations. For set 9, which is used for Region A, Q represents peak flow in cubic feet per second, A is drainage area in square miles, S is channel slope in feet per mile, and L is channel length in miles. For set 10, which is used for Region B, P represents mean annual precipitation in inches, and E represents mean basin elevation in feet. Northwest Arkansas lies in Region B.

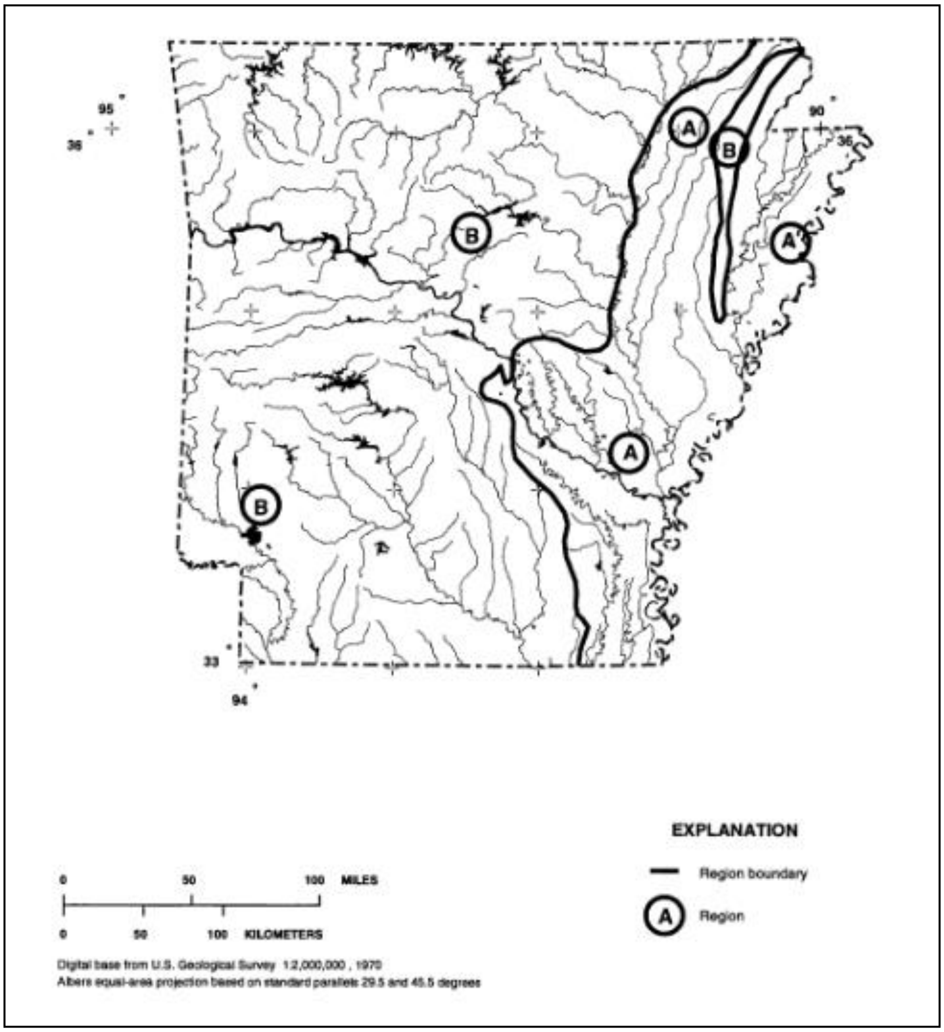

Figure 7. Flood-Frequency Region Map for Arkansas (Riggs and Thomas, 1993)

$$
\begin{aligned}
Q2 &= 107A^{0.83}S^{0.28}L^{-0.33} \\
Q5 &= 149A^{0.88}S^{0.36}L^{-0.40} \\
Q10 &= 175A^{0.83}S^{0.28}L^{-0.33} \\
Q25 &= 205A^{0.83}S^{0.28}L^{-0.33} \\
Q50 &= 226A^{0.83}S^{0.28}L^{-0.33} \\
Q100 &= 245A^{0.83}S^{0.28}L^{-0.33}
\end{aligned}
\qquad \text{Equation 9}
$$

$$
\begin{aligned}
Q2 &= 0.120A^{0.78}S^{0.42}(P-30)^{0.55}E^{0.75} \\
Q5 &= 0.521A^{0.78}S^{0.48}(P-30)^{0.43}E^{0.64} \\
Q10 &= 1.07A^{0.78}S^{0.51}(P-30)^{0.38}E^{0.59} \\
Q25 &= 2.23A^{0.79}S^{0.53}(P-30)^{0.33}E^{0.53} \\
Q50 &= 3.58A^{0.79}S^{0.55}(P-30)^{0.29}E^{0.50} \\
Q100 &= 5.35A^{0.79}S^{0.56}(P-30)^{0.27}E^{0.47}
\end{aligned}
\qquad \text{Equation 10}
$$

2.3.4 Gage Stations

The United States Geological Survey (USGS) operates about 9,000 stream-gage stations around the country (Lurry, 2011). These gage stations collect data for stream flow that includes gage height (in inches), precipitation (in inches), and discharge (in cubic feet per second). Data is continuously collected and logged at 15 minute intervals. All stream flow information is available from USGS online at http://waterdata.usgs.gov/nwis/rt.

2.3.5 Log-Pearson Type III Frequency Analysis

The Log Pearson Type III (LP3) Frequency Analysis is the most commonly used statistical distribution technique in hydrology (McCuen, 2005). It plots annual maximum peak flow data as a function of return period (in years) and exceedence probability (in percentage). This plot is prepared by taking the $\log_{10}$ of annual maximum peak flows, calculating the mean, standard deviation, and standardized skew for the data series of peak flows, and determining the LP3 curve value for each peak flow by using Equation 11, where X is the LP3 curve logarithmic value, $\bar{X}$ is the mean of the series, K_N is the standardized variant known for a sample size N, and S is the standard deviation (USGS, 1982).

$$X = \bar{X} + K_N S \qquad \textit{Equation } 11$$

The values of K for various N values are available in Bulletin 17b, a guideline for determining flood flow frequency, published by the U.S. Geological Survey (1982). The antilogarithm of X is the computed discharge for the given exceedence probability.

It is common practice to use USGS gage station data in conjunction with the LP3 frequency analysis to predict the peak flow for storm events at a specific gage. For example, in the aforementioned Idaho study, peak flows were calculated by using the LP3 analysis for annual peak flow data at gaged sites (Berenbrock, 2002).

2.4 Controlling Stormwater Runoff

Many methods exist for controlling the various parameters of stormwater runoff. Stormwater issues have resulted from increased runoff volume during storm events. A main area of concern for runoff control is the discharge volume received by a stream during events. When precipitation falls in urban areas, the large area of impervious surface inhibits infiltration and causes the amount of runoff to increase. This increased runoff then flows to the stream and increases the flow discharge.

One study (Klein, 1979) provided four options to reduce the adverse affects of urbanization on stream quality. The first, detention and retention systems, were suggested in order to reduce the peak flow of runoff and the scouring resulting from higher flow rates. A study in Australia suggested similar systems, indicating that complete retention of runoff from storm events would decrease the amount of pollutants entering the stream and reduce the undesirable effects of runoff (Walsh, Fletcher, and Ladson, 2005). This retention system could allow for infiltration, evapotranspiration, or reuse of the captured runoff.

Walsh et al. suggested designating impervious surfaces as “disconnected” from the urban stream. In this way, the runoff from these surfaces would be captured and disposed of in ways other than discharge to the stream. The Klein study (1979) also suggested infiltration systems that could minimize the runoff volumes directly entering the stream. Infiltration systems in conjunction with stormwater retention could effectively reduce stormwater runoff volume and quality impairment in streams.

The amount of retention required for effective stream improvement can be found using a number of methods. In the Walsh et al. study (2005), retention volume was estimated by first estimating the runoff volume from an undeveloped area of land and the rain event associated with that amount of runoff. This was then compared to the runoff in the urban area of interest to determine the volume of storage required.

Stormwater treatment systems were also suggested by Klein (1979) in order to increase the quality of runoff prior to reaching the stream. According to an EPA study (Winer, 2000), types of stormwater treatment include ponds, wetlands, open channel treatment, water filtering, and infiltration. Ponds can be either wet or dry, and treat water by pollutants settling, being adsorbed by sediment, and being taken up by plants (Krishnappan et al., 1999). Settling, adsorption, and plant uptake also take place in wetlands, as well as pollutant degradation through microbial processes (Scholes, Revitt, and Ellis, 2008). Open channel treatment includes swales and grass channels, which allow for adsorption, plant uptake, and filtration by soil. Constructed filters with filtrates such as sand capture pollutants as the water flows through it. Similarly, infiltration zones and trenches allow for adsorption of pollutants and some microbial degradation (2008).

The last suggestion of the Klein study (1979) was to limit watershed development and restrict the amount of impervious cover in the area in order to reduce the amount of runoff produced by the watershed. Another study agreed that reduction of impervious cover could effectively improve a stream's quality (Walsh, Fletcher, and Ladson, 2005). A variety of practices have been utilized to decrease the amount of impervious cover in areas. These include reduction of conventional pavement amounts, use of porous pavement, implementing grass buffers in areas of imperviousness, and implementation of infiltration systems such as porous cascading panes (Guo, 2008).

2.5 Stormwater Detention Design

Stormwater detention facilities serve the purpose of temporarily holding runoff so that flow rates of a stream do not increase above a desired level. Commonly, municipalities will require that the post-development peak flow rate not exceed the pre-development flow rate, and detention ponds are designed to capture the extra flow so that this requirement is met (Goff and Gentry, 2006). The city of Fayetteville requires that detention be provided for the 100-year event. The University of Arkansas, being owned by the state of Arkansas, is not legally obligated to comply with their requirements (AHTD, 1982). According to the AHTD manual, however, the State may follow local ordinances as a "matter of courtesy".

Various methods have been developed that calculate storage volume, release rate, and outlet specifications based on requirements of the municipality in which the detention facility is to be constructed. General parameters are utilized for these methods (McCuen, 2005). These parameters are ratios that compare peak flow rates (q_p) and times of concentration (t_c) for pre-development conditions (b) and post-development conditions (a). These ratios are presented in Equations 12 and 13.

$$\alpha = \frac{q_{pb}}{q_{pa}} \qquad \textit{Equation } 12$$

$$\gamma = \frac{t_{cb}}{t_{ca}} \qquad \textit{Equation } 13$$

The volume of storage need (V_s) in inches can be calculated using Equation 14, where Q_a is the post-development runoff depth.

$$V_s = \left(\frac{\gamma + \alpha + \alpha\gamma(\gamma + \alpha - 4)}{\gamma - \alpha}\right) Q_a \quad for\ \alpha < 2 - \gamma \qquad Equation\ 14a$$

$$V_s = \left(\frac{\gamma - \alpha}{\gamma + \alpha}\right) Q_a \qquad for\ \alpha \geq 2 - \gamma \qquad Equation\ 14b$$

To convert volume of storage to acre-feet, Equation 15 can be used, where A is the drainage area in acres.

$$V_{st} = \frac{V_s A}{12} \qquad Equation\ 15$$

Various methods utilizing these equations have been used often in hydrologic design and are discussed below.

2.5.1 Loss-of-Natural-Storage Method

The Loss-of-Natural-Storage Method equates the needed storage volume to the difference in runoff depths between pre- and post-development conditions, as shown in Equation 16 (McCuen, 2005).

$$V_s = Q_a - Q_b \qquad Equation\ 16$$

According to McCuen, the runoff depths (Q) can be estimated either by Equation 3 for the SCS Method or by using Equation 17, below, for the Rational Method. Q is in inches, q_p is peak discharge in cubic feet per second, t_c is the time of concentration in minutes, and A is drainage area in acres.

$$Q = \frac{2}{121}\left(\frac{q_p t_c}{A}\right) \qquad Equation\ 17$$

2.5.2 Rational Formula Hydrograph Method

The Rational Formula Hydrograph Method uses the concept of hydrograph differences to calculate volume of storage needed (McCuen, 2005). Equation 18 displays the calculation for storage volume in inches. The peak discharges are in cubic feet per second, time of concentration is in hours, and drainage area is in acres.

$$V_s = \frac{(q_{pa} - q_{pb})t_{ca}}{A} \qquad \text{Equation 18}$$

According to some literature, the Rational Method of sizing detention ponds is best used for small ponds at the subdivision level of development (Aron and Kibler, 1990).

2.5.3 SCS TR-55 Method

The Soil Conservation Service (now known as the Natural Resource Conservation Service) provides a method for storage volume calculation through its Technical Release 55 (NRCS, 1986). This method is used in conjunction with the NRCS peak flow determination method described previously.

The ratio of storage volume to post-development runoff depth is calculated with Equation 19. Coefficients are a function of the rainfall distribution type and are given in Table 1.

$$R_s = \frac{V_s}{Q_a} = C_0 + C_1\alpha + C_2\alpha^2 + C_3\alpha^3 \qquad \text{Equation 19}$$

Table 1. SCS TR-55 Method Coefficients for Rainfall Distribution Types (McCuen, 2005)

Rainfall Distribution Type	**C_0**	**C_1**	**C_2**	**C_3**
I or IA	0.660	-1.76	1.96	-0.730
II or III	0.682	-1.43	1.64	-0.804

The volume of storage in acre-feet can be determined by using Equation 15.

2.5.4 Stormwater Storage Alternatives

According to the Environmental Protection Agency (EPA), dry detention ponds are a traditional and widely utilized best management practice (BMP) (EPA, 2006). The EPA fact sheet on these ponds discusses that detention ponds are difficult to apply in urban areas, however, as there is less land area available. For areas where the construction of a detention pond is possible, the EPA lists guidelines. First, dry detention ponds should be used for capturing runoff for an area of at least 10 acres. Also, the slope of the construction site should be less than 15 percent. The pond should also not intersect the ground water table.

In addition to location requirements, the EPA lists design considerations, which are given below (2006).

- Stormwater pretreatment through particle settling
- Stormwater treatment by detaining stormwater for a between 12 and 48 hours to maximize treatment
- Conveyance of runoff through the pond to minimize erosion and scour
- Minimization of pond maintenance
- Landscaping with appropriate plants

The detention pond is a common storage facility, but other storage alternatives exist. According to the EPA (2001), underground storage systems are used, especially in areas where land is not available for conventional ponds. Some tanks release captured water back to a stream over time, while others allow for infiltration into the soil below. Commercial products are commonly used and are specifically designed to withstand loads that include parking lot material and vehicles. Due to the need for excavation and material costs, underground tanks can be much more expensive than surface storage structures, but when conventional storage is not possible, the underground tanks can be very applicable to drainage needs.

2.6 Army Corps of Engineers Hydraulic Engineering Center Stormwater Modeling

The Army Corps of Engineers Hydraulic Engineering Center (HEC) has released a number of stormwater modeling software over the years to the public, free of charge. These software programs offer a variety of services, including watershed modeling, stream modeling, and storm event flow modeling.

The HEC Statistical Software Package (HEC-SSP) performs statistical analyses on hydrologic data (USACE, 2009). It can perform a flow frequency analysis, generalized frequency analysis, and a volume-duration frequency analysis based on data that can either be imported from USGS gage stations or manually entered. HEC-SSP can provide flow-frequency curves such as the LP3. In SSP, the LP3 study is entitled the Bulletin 17B flood flow analysis, named for the analysis guidelines published by USGS (USGS, 1982). Many drainage studies have utilized this software. For example, rainfall depths for various storm events were determined in a hydrologic analysis of Sana'a, Yemen, in an effort to better understand flood patterns in the city (Root and Papakos, 2010). A fish habitat restoration project in California utilized HEC-SSP in order to determine design flows at various return periods for the stream to be restored (NCRCD, 2006).

The HEC River Analysis System (HEC-RAS) allows the user to perform one-dimensional steady and unsteady flow analyses on a stream by inputting geometrical characteristics of the channel (USACE, 2008a). The RAS program can also model sediment transport and temperature changes. Outputs for RAS include water surface elevations for various flow rates, flow distributions across a channel, and graphical representations of the stream's profile. Many studies utilize HEC-RAS for the purpose of hydraulic analyses. For example, the North Little Rock Stormwater Management Analysis utilized HEC-RAS in order to determine the water surface elevations in various channels (Carter-Burgess, 1998).

The GeoRAS extension is a toolset for use in GIS (Geographical Information System) that processes geospatial data and formats it for import to HEC-RAS (USACE, 2011). A digital elevation model (DEM) can be created in ArcMap, a software program enabling the user to view and manipulate GIS data. This model is a representation of the surface elevation of an area and displays continuous terrain values (Wade and Sommer, 2006). Once a DEM is created, the ArcMap HEC-GeoRAS toolbar may be used to process terrain data for channels, cross-sections, lateral structures, storage areas, and other stream data. In one study of floodplains along the Columbia River in Washington, GeoRAS was utilized to define and export cross-section elevations after creating a DEM model for the area (Wands et al., 2010). An early flood warning study also utilized GeoRAS to define 440 cross-sections for a channel (Matkan et al., 2009). Survey data of channel cross-sections and structures can also be used in HEC-RAS in addition to GeoRAS data, as was done in a hydraulic model of the Purgatoire River in Colorado (Klumpp and Garcia, 2010).

HEC-HMS, the HEC Hydrologic Modeling System, is used to model runoff throughout watersheds (USACE, 2008b). Inputs include basin area and other characteristics such as curve number and lag time. Outputs include hydrographs and values for peak discharge, time to peak, and volume for each basin. Studies such as the one in Misai and Wan'an, China, used HEC-HMS to model catchments and predict future flooding (Oleyiblo and Li, 2010).

2.7 Stream Restoration

The United States Environmental Protection Agency (USEPA) defines restoration as a return of a degraded ecosystem to a close estimate of its natural potential (USEPA, 2000). This can be specifically applied to stream ecosystems. The term "stream restoration" has been used to describe a wide range of actions. Some consider any positive renovation of a stream to be a restoration, while others only consider a full reestablishment of a stream's ecosystem to be an actual restoration. According to a USDA (1998) document on stream corridor restoration, a full restoration is a “reestablishment of the structure and functions” of an ecosystem. Stream rehabilitation, however, is defined as a “recovery of ecosystem functions and processes.” The main difference between restoration and rehabilitation is that a restoration attempts to return an ecosystem to ”predisturbance” conditions, while rehabilitation attempts to recover some lost functions in a “degraded” ecosystem without fully returning it to its original condition (1998).

Full-scale restoration is again defined as a return of the ecosystem to its pre-disturbance state (NRC, 1992). This type of restoration is considered by many to be unrealistic and, in many cases, impossible (Moerke and Lamberti, 2004). This is due to the fact that streams in the United States have experienced dramatic alterations in the past decades, and little or no historical information exists to defined their original states. Also, with the large amount of development in many urban areas, the possibility of eliminating the developments in order to restore the stream is nonexistent. In order to remediate a stream, other avenues must be explored. Some studies such as the Walsh et al. study (2005) suggest that stormwater drainage is the “constraining factor” for stream restoration in an urban setting, and that stream restoration should be centered on reducing storm drainage to streams (both through runoff and pipes).

2.7.1 Stream Restoration Methods

There are a variety of stream restoration methods that have been implemented in streams around the world with favorable results. Step-by-step methods have been developed by researchers and designers in order to give a basis for the design of any stream. These methods are general and must be applied on a stream-to-stream basis to achieve a stream-specific design.

2.7.1.1 Rosgen Method

The Rosgen Method involves the restoration of the “dimension, pattern, and profile” of a stream by comparing it to and emulating the characteristics of an undisturbed, stable stream

(NRCS, 2007a). The major steps of the Rosgen design method include (1) defining restoration goals, (2) developing site characteristics including geomorphology, hydrology, and hydraulics, (3) collecting field data including sedimentation and stream morphology, (4) consideration of passive restoration methods, (5) design of a channel using hydraulic and sediment transport analysis, (6) selection of various stabilization methods to meet the goals, (7) Implementation of the design , and (8) monitoring the restored stream for effectiveness. Rosgen developed a classification system for streams based on entrenchment ratio, width/depth ratio, sinuosity, slope, and channel material (Rosgen, 1996). This system is used to classify the impaired stream and compare it to an undisturbed stream of the same type. A Rosgen classification chart is displayed in Appendix B. The Rosgen method also involves the development of regional curves, which incorporate data from multiple streams in the same geological region and is used to find average bankfull discharge, depth, width, and cross-sectional area of a stream based on drainage area. The design of the restored stream involves calculations of riffle and pool lengths, depths, and radius of curvature of stream turns based on the bankfull width and other parameters determined from regional curves.

The Rosgen Method utilizes references reaches to obtain stable stream characteristics that can be applicable to the stream design process (Rosgen, 1998). Rosgen lists 25 parameters that should be measured when assessing a reference reach and comparing it to the design stream, including bankfull width, sinuosity, drainage area, depths and widths of pools, riffles, runs, and glides. These reference reach parameters are used to calculate ratios that are then applied to the stream design process.

Though the Rosgen Method is widely used, critics have identified issues with the system. One critique is the use of bankfull stage as an important parameter. Simon et al. (2007) suggest that bankfull level in unstable streams can be difficult to identify correctly due to problems such as erosion. In these streams, a depositional area is not always apparent due to lack of stable sediment transport and changing channel dimensions. Another problem this study found with the Rosgen Method is the dominant material classification, which is criticized due to the fact that material and the way it travels differ across a channel. Incorrect bed material classification can lead to incorrectly identifying channel type and necessary restoration parameter values. The study concludes that while the Rosgen Method is a useful technique in classification and stream comparison, it should not be used as a general design procedure for all stream types.

2.7.1.2 Other Stream Design Methods

More generalized methods for stream restoration exist. The National Engineering Handbook defines three basic methods: analogy, hydraulic geometry, and analytical design (NRCS, 2007b). The analogy design method develops channel dimensions from a reference reach. A reference reach is a “stable” stream segment that is similar in hydrology to the design stream (Harman and Jennings, 2001). A stream is considered stable if it does not “exhibit abrupt, episodic, or progressive changes” in its physical characteristics (Shields et al., 2003).

The hydraulic geometry design method uses regression relationships to determine channel dimensions. Regional regression curves are developed from stable streams with similar physiology to the stream of concern. Usually, relationships between geometric parameters are based on a discharge such as the bankfull discharge (Niezgoda and Johnson, 2005). The regional curves are created in the form of graphs that are then used to find a design parameter based on a known parameter for the design stream, such as drainage area. For example, Figure 8 displays an example of a regional curve for bankfull depth for a stream region in Pennsylvania and Maryland.

Both the use of reference reaches and regional curves have been questioned for use in urban settings because the effect of land use on stream morphology is very significant (Niezgoda and Johnson, 2005). It is suggested that local conditions, vegetation, morphology, and other site-specific issues be taken into account when designing for urban streams.

In the analytical method, equations are utilized to calculate depth and sediment transport through the stream. The Rosgen Method identifies many equation used to calculate shear stress on sediment, bankfull depth in relation to particle size, and water surface slope (NRCS, 2007a). These equations and others are commonly used to size stream bed particles to prevent destructive erosion and deposition.

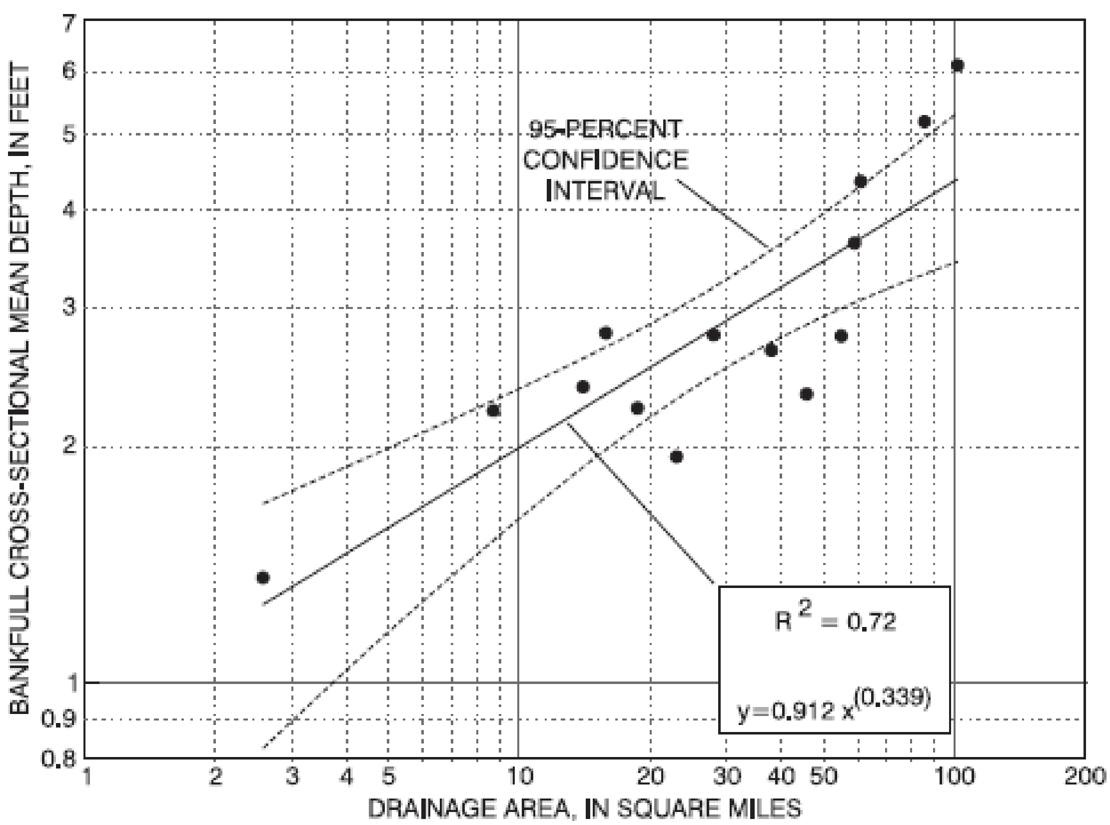

Figure 8. Regional curve relating bankfull mean depth to drainage area for non-urban Piedmont Physiographic Province, Pennsylvania and Maryland (Cinotto, 2003)

Hybrid design methods have arisen from the three basic methods discussed previously. The Rosgen method is one of such methods. Another is the two-stage channel design method. In a two-stage channel, the main channel is designed to carry the “dominant” discharge, while the secondary channel provides a flood plain (NRCS, 2007c). Advantages of this design method include improved channel stability and reduced channel maintenance. The method suggests that the flood plain width be three to five times the main channel width to allow for channel bank and path stability.

2.7.2 Stream Restoration Techniques and Structures

There are many types of design techniques and structures that can be applied to stream restoration. The type of structure used depends upon the disturbance type, location, budget, and time constraints.

A review by the Center for Watershed Protection in Maryland (Brown, 2000) suggests that restoration practices can be divided into four groups: bank protection, grade control, flow deflection, and bank stabilization. Bank protection includes rip-rap, rootwad revetments, boulder revetments, lunkers, and a-jacks. The purpose of protection is to decrease erosion potential and stabilize the location of the bank and channel. Roseboom et al. (1999a) performed a rehabilitation project to protection and stabilize a stream’s banks and utilized lunkers, which are wooden box-like structures that are keyed into a bank and covered with rip-rap and rebar for stabilization. These structures not only protected the stream banks, but also provided habitat for in-stream organisms.

Rip-rap is a collection (or “blanket”) of strategically placed rocks that help to protect a stream bank from erosion and scour (FHA, 1989). As described by HEC-11 (FHA, 1989), rock rip-rap is the “most desirable type of revetment in the United States.” This desirability is due to the flexibility of the rip-rap “blanket”, ease of repair, simplicity of construction, ability for vegetation to grow through and around the rock structure, and recoverability of material. Design of a rip-rap structure should consider multiple flow rates, usually the 10- and 50-year events. In order to size the rocks, Equation 20 (FHA, 1989) can be used, where D_{50} is the median rip-rap particle size (ft), V_a is the average velocity in the main channel (ft/s), d_{avg} is the average flow depth in the main flow channel (ft), and K_1 is a factor calculated using Equation 21. Θ represents the bank angle with the horizontal, and φ represents the rip-rap angle of repose.

$$D_{50} = \frac{0.001V_a^3}{d_{avg}^{0.5}K_1^{1.5}} \qquad Equation\ 20$$

$$K_1 = \left(1 - \frac{sin^2\theta}{sin^2\phi}\right)^{0.5} \qquad Equation\ 21$$

The angle of repose is the angle that the stones will lay with the bank, and this angle should be greater than the slope of the bank.

One commonly used stream structure is the pool and riffle system. Pool-and-riffle systems can improve stream stability and fish habitat (Newbury and Gaboury, 1999). Pools are normally located in the thalweg in a stream bend, while a riffle is usually located between two bends (FISRWG, 1998). Pools and riffles occur alternately down a stream reach. According to Newbury and Gaboury, average length between two riffles or two ponds should be eight to twelve times the bankfull width (1999). More in depth design procedures are found in the *Field Manual of Urban Stream Restoration* (1999).

Similar to the pool and riffle system is the step-pool system. A step-pool system is more common in a stream with little meandering and steeper slope. The steps are used as grade stabilization and the pools absorb excess energy (FISRWG, 1998). Step-pool systems can also add habitat diversity. In a stream restoration project in California, step pools were added to improve slope stability and were designed to avoid undercutting between the pools and steps (Purcell, Friedrich, and Resh, 2002). While step-pools are more common in streams with steeper slopes, they can also be used in streams with lesser slopes in order to dissipate energy and decrease flow rates after land-use changes (Chin et al., 2009).

Grade control includes step-pools, mentioned previously, as well as rock weirs and cross vanes. A cross vane decreases shear stress and velocity near stream banks and establishes grade control by directing flow toward the center of the stream and creating a pool for energy dissipation (Rosgen, 2001). A weir provides the same effect in larger streams.

Flow deflection includes wing deflectors, log and rock vanes, and cut-off sills. These methods all work in the same manner, causing the stream's flow to deflect away from the banks.

Bank stabilization includes vegetation in the form of plants, coir fiber logs, and brush mattresses. These methods of stabilization reinforce the soil and protect the surface from erosion and scour (Li and Eddleman, 2002). Riparian vegetation, which provides streamside habitat and natural water filtering, can prevent erosion by holding the soil in place with its roots and absorbing stream energy and decreasing flow velocity. Lack of vegetation can be a cause of degradation along the stream (FISWRG, 1998).

The best choices for riparian vegetation are local plants that are "resilient" to high flows (FISWRG, 1998). The plants should be planted outside of the floodplain, along the topsides of the banks. Trees such as dogwoods and willows are able to withstand higher flows and are used in many rehabilitation projects (Roseboom et al, 1999b).   Black willows (*Salix nigra)* are a native tree of Arkansas and are common in wetlands (USFWS, 1999). According to Steyermark's *Flora of Missouri* (1981), black willow trees occur along streams and other bodies of water, and are a commonly found species ranging from New Brunswick, Canada, to Texas.

This type of willow grows well in the Ozark region in alluvial soils of mud and silt found outside of the actual stream bed, in the riparian zone of the stream. Black willows naturally reinforce stream banks and help control erosion. Rough-leaved dogwoods (*Cornus drummondi)* are also common in Arkansas and can be found along streambanks (1981).

2.8 Previous Studies on College Branch

Many studies have previously been performed on College Branch for both scholastic and developmental purposes. These studies involved analysis of College Branch and its watershed as well as suggestions for improvement of the stream and watershed.

2.8.1 University of Arkansas Community Design Center

In 2005, the University of Arkansas Community Design Center (UACDC) published a 117-page document that provided an overview of College Branch and its problems, as well as design suggestions. The study listed design considerations for stream remediation, including widening of the floodplain, stream bank regrading, increased stream sinuosity, riparian zone installment, and reduction of runoff volumes (UACDC, 2005). Their design proposals included the return of land allocated for parking (Lot 56) to a wetland status, with a parking deck built over it. It also proposed building a visitor's and transit center that included an educational display involving ecosystem restoration and protection. This design idea incorporated environmental concerns with the requirements of the university in terms of parking. This design, though goal-oriented, is above financial feasibility.

2.8.2 Undergraduate Study using ArcGIS

A 2008 study performed by Koehn, a University of Arkansas undergraduate student, provided useful ArcGIS data regarding the watershed, as well as present-day characteristics of the watershed (Koehn, 2008). Koehn's work concentrated on developing a stormwater runoff prediction model for use in watershed's such as College Branch. Koehn utilized ArcGIS to delineate the watershed from the NRCS HUC 12-digit watershed. Storm drainage information obtained from the University of Arkansas Facilities Management (FAMA) was also imported into ArcGIS, as well as land use and land cover data and soil properties data for the watershed. Subwatersheds within the College Branch watershed were delineated using ArcHydro, and were based on both surface flow and pipeline flow of the stormwater drainage network. Koehn then generated curve numbers for the study area using the NRCS curve number (CN) method. In order to determine the curve numbers for the subwatersheds in the area of interest, the land use and land cover for each watershed was determined. The present-day land use/land cover (LULC) data was acquired from the Arkansas Geological Information Systems (GIS) website (www.geostor.arkansas.gov). The acquired LULC data was a raster, or pixilated, file with LULC data for Fall 2006, which was the most recent available data at the time of research. The soils data for the watershed was acquired from the NRCS SSURGO database for 2007 data. The data imported into ArcGIS was utilized by Koehn to determine the present-day curve number for each subwatershed in the College Branch Watershed.

2.8.3 Undergraduate Conceptual Design for Stream Stabilization

A third study performed by the author and another undergraduate student (Logsdon), included an analysis of College Branch and its surrounding area and conceptual design ideas for improvements to the area. The analysis included visual studies, a water quality study, a stream physiology study, and an ecosystem services study. Conceptual design ideas included stream restoration at certain points along the stream and a design proposal for water quality improvement in parking lot runoff (Logsdon and McCoy, 2009).

3. METHODOLOGY

3.1 Runoff Analysis

In order to analyze the runoff potential for the College Branch Watershed, steps were required. First, the watershed was divided into subwatersheds in order to more accurately analyze its characteristics. The Koehn study (2008) performed on the College Branch Watershed provided subwatershed delineation based on both surface and subsurface flow. Koehn's delineation was performed in ArcGIS and produced 50 delineated subwatersheds. These subwatershed boundaries are displayed in Figure 9.

The current study was performed in order to identify areas of concern on the University of Arkansas campus so that campus developers would be better informed on immediate drainage needs and future considerations. Therefore, only the subwatersheds north of Highway 62 that contribute to the flow of College Branch while on the University of Arkansas campus were considered. These subwatersheds were determined using a contour map of the watershed to analyze the direction of flow for each subwatershed. A map identifying the flow path of each subwatershed is shown in Figure 10. The subwatersheds of concern were then identified as those with flow paths that led to subwatersheds containing College Branch. Appendix C contains a map identifying these subwatersheds as well as a map displaying only the contours and watershed boundaries.

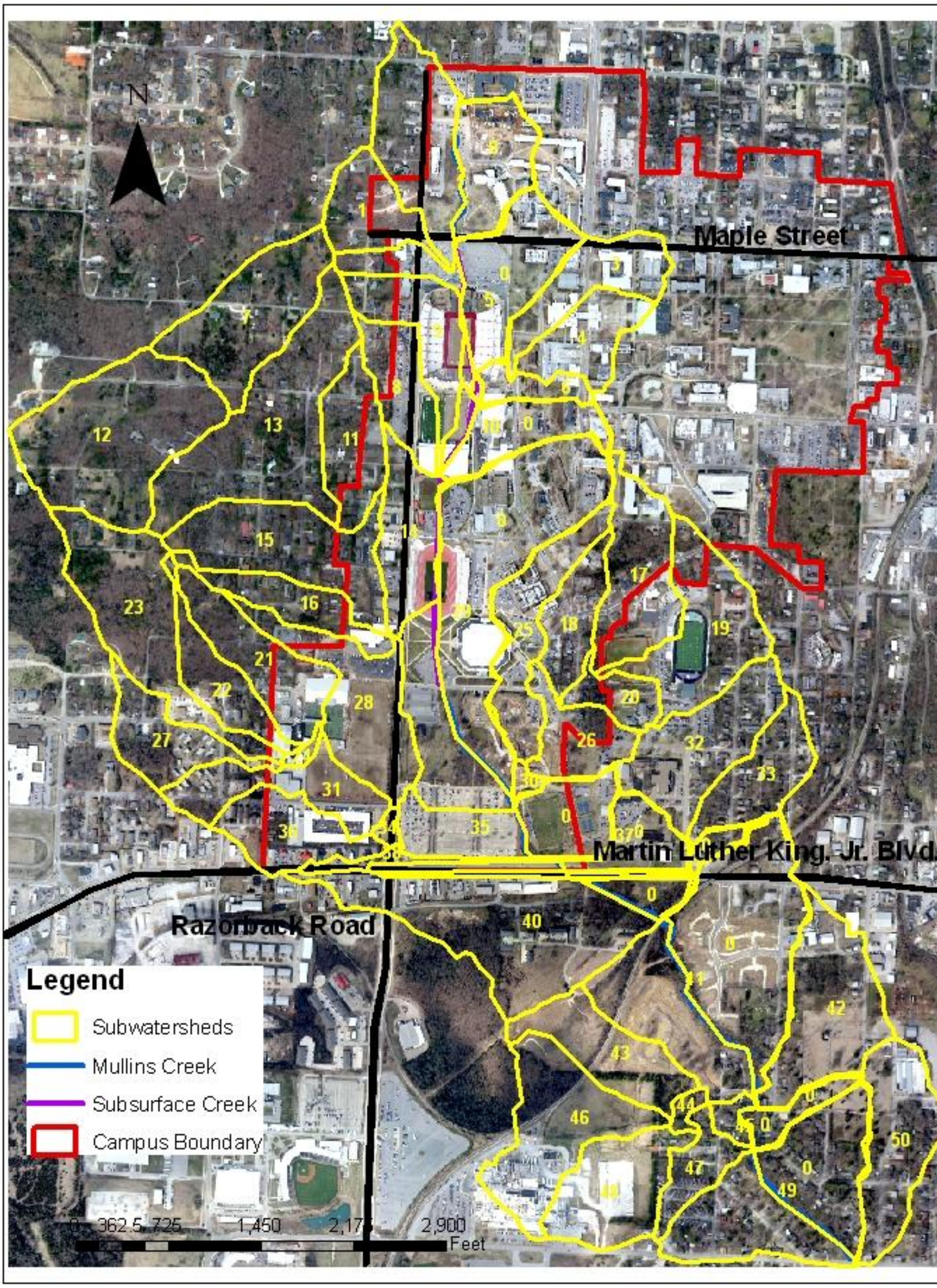

Figure 9. Aerial view of College Branch Watershed with subwatersheds defined

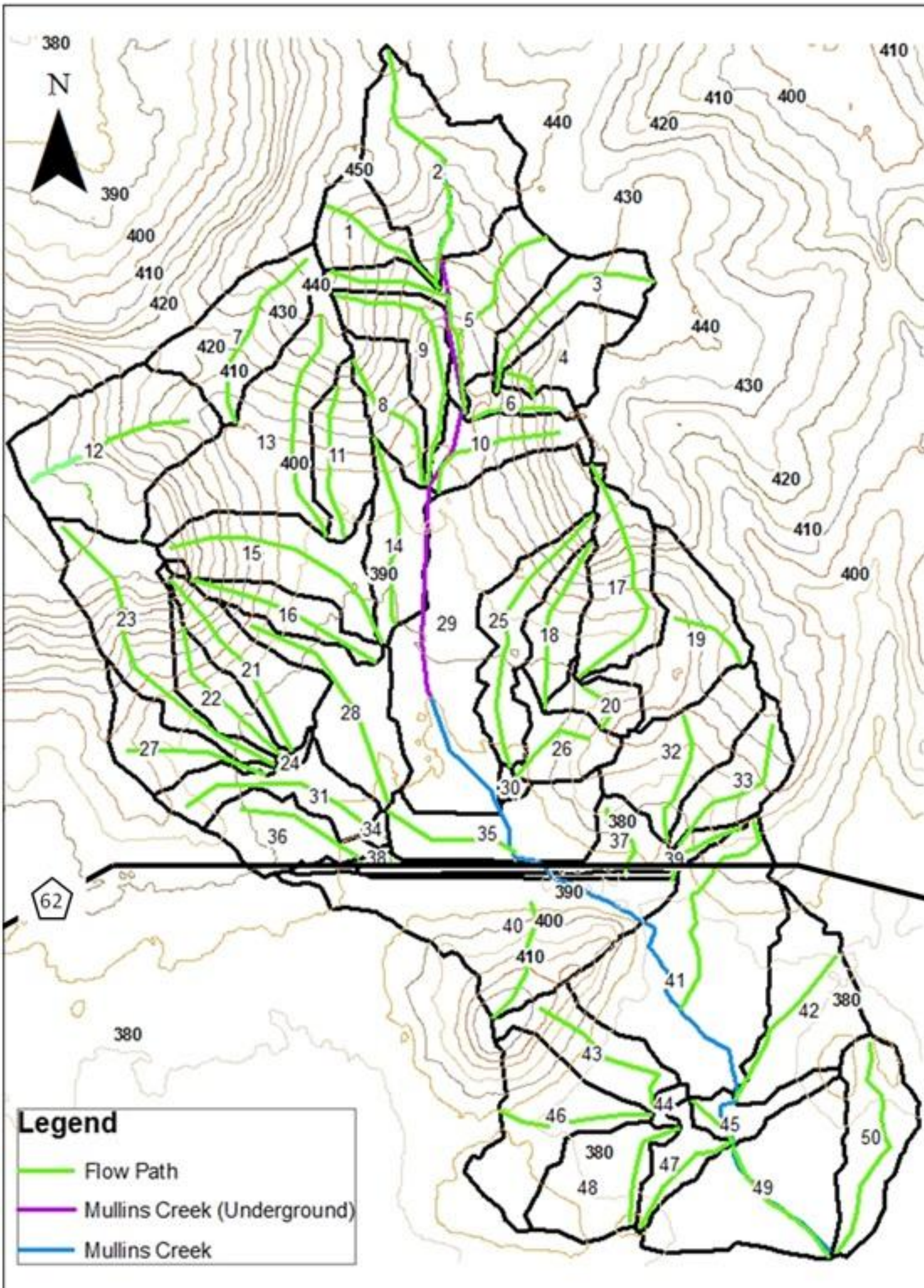

Figure 10. Contour and flow path map of College Branch Watershed

As described in the Literature Review, a variety of methods exist for analyzing runoff. The statistical methods available included the Rational and NRCS Methods, as well as regional regression methods. The Rational Method was not considered due to the fact that it was recommended only for areas of less than 200 acres and for 5 and 10-year storms. Therefore, the NRCS Method was conducted as the statistical method of choice. The NSS Program flood frequency equations for Arkansas were also used in order to calculate runoff statistically. Since a USGS gage station exists on College Branch at the most downstream end of the study reach, a deterministic analysis of runoff was also conducted.

3.1.1 NRCS Method

The NRCS Method for determining runoff is based on the curve number (CN). The CN was determined for each subwatershed in the Koehn study (2008) based on soil type, antecedent moisture conditions (AMC), and land use. The CN for each subwatershed for AMCI, AMCII, and AMCIII is given in Table D1 in Appendix D. These CN were checked for validity by comparing to the conditions of each subwatershed and CN tables in TR-55 (NRCS, 1986).

In order to perform calculations, the antecedent moisture content (AMC) for the watershed was chosen. According to McCuen (2005), AMCI represents dry soils, AMCII represents average conditions, and AMCIII represents saturated soil due to heavy rainfall or a combination of rainfall and low temperatures. Though College Branch Watershed can experience all three conditions throughout the year, the AMC used in the runoff and storage volume calculations should represent that which will incur the highest value for runoff so that the design will be effective in the most extreme conditions. Therefore, the AMCIII conditions were chosen due to the fact that saturated soil will lead to a higher value of runoff because the surface will be less pervious.

Using the assumed AMCIII CN for each watershed, the potential maximum retention, S, was calculated using Equation 1. The initial abstraction, I_a, was calculated using Equation 2. The calculated S and I_a for each watershed are given Table D2 in Appendix D. The rainfall amounts for each storm were found using the National Weather Service (NWS) Technical Paper 40 (TP-40) maps, available in NRCS Technical Release No. 55 (TR-55) (NRCS, 1986). An intensity-frequency-duration (IDF) curve was also created using this information. Intensity was calculated using Equation E1 in Appendix E. The values for rainfall and intensity at various durations and the IDF curve are also given in Appendix E.

Knowing the rainfall values (P) for 24-hour duration storms, the runoff depth (Q) was calculated using Equation 3b. The values for Q of each subwatershed for each storm event are given in Appendix F.

In order to calculate peak flow, Equation 4 was utilized. First the unit peak discharge was needed, which is a value found graphically knowing the initial abstraction to precipitation (I_a/P) ratio, the rainfall distribution type, and the time of concentration. The I_a/P ratio is given in Appendix F. The rainfall distribution type was found using the rainfall distribution map available in TR-55 (NRCS, 1986). This map shows that Fayetteville, AR, lies in the Type III area. The time of concentration is dependent on the type of flow in each subwatershed. The type of flow for each section of each watershed was determined by visual analysis (whether a channel was present or not). If the longest flow path was determined to not be channel flow, the first 300 feet of flow were identified as sheet flow and the remaining as shallow concentrated flow. The Manning's n was determined using a land use/land cover map of the watershed and comparing to Manning's n values for each land cover in the flow path of each subwatershed. Manning's n values for various land uses were available in TR-55 for both sheet flow and channel flow.

Appendix G contains a land use/land cover map of College Branch Watershed. A chart identifying the type of flow, flow length, Manning's n, and slope for each subwatershed is given in Appendix H.

Once the type of flow was determined, the times of travel were calculated. For sheet flow calculations, the 2-year, 24-hour precipitation value was needed. From TR-55 maps (NRCS, 1986), the 2-year precipitation for Fayetteville, AR, is 4.1 inches. Using this data, the time of travel for flow lengths with sheet flow was calculated using Equation 5. For flow lengths with shallow concentrated flow, the curve given in TR-55 was used. The flow paths were determined to be pave or unpaved using aerial maps. The velocities for flow paths that experienced both paved and unpaved conditions were averaged between the two condition values. After using the curve to find velocity, the time of travel was calculated using Equation 6. For channel flow, the cross-sectional area and wetted perimeter of the channel were required. This data was acquired from a stream survey performed by Logsdon and McCoy (2009) in the 2009 study on College Branch. This survey included cross-section measurements at various points along the stream, with water surface elevation for base flow conditions. The 2009 survey data is available in Appendix I. Other open channels are present in the watershed in the form of drainage ditches. The geometrical data for these ditches were determined through field reconnaissance by the author. The cross-sectional areas were calculated by dividing the cross-sections into segments using the survey points, averaging the depths between the points, and multiplying by the width between the points to find the area. The wetted perimeters were determined by calculating the distance between data points in the wet channel. For the length of flow in Subwatershed 2 that is channel flow, the data for cross-sections 1, 2, and 3 was averaged. Cross-sections 4, 5, 6, and 7 were average for Subwatershed 29, and cross-sections 8, 9, and 10 were averaged for the channel flow in Subwatershed 35. The velocities were then calculated using Manning's Equation (Equation 7), and the times of concentration were calculated with Equation 6.

A large portion of runoff on the University of Arkansas campus is captured by storm drains that direct flow into underground pipes. The longest flow length of some of the subwatersheds is through underground pipes, and therefore pipe flow was considered for these subwatersheds. In order to calculate the velocity of flow through pipes, the radius of the pipe (r) and the depth (h) of water in the pipe were needed. The pipe sizes were determined from pipe schematics acquired from the U of A Facilities Management (FAMA). The schematics are given in Appendix I. Knowing the pipe geometry, the central angle, cross-sectional area, and wetted perimeter were determined. The velocities and times of concentration for these flow paths were found with Equations 6 and 7. The needed parameters and the calculated times of concentration for each flow type in each subwatershed are given in Appendix H.

With the times of concentration calculated, the unit peak discharge was determined for each subwatershed with unit peak discharge curves. The calculated I_a/P values were less than 0.1, but no curve exists for these values, the 0.1 curve was used to determine the peak unit discharge. Also, for some subwatersheds the times of concentration were below 0.1, so 0.1 hour was used in these cases. The determined values for unit peak discharge are given in Appendix J.

With the runoff depth (Q), drainage area (A), and unit peak discharge (q_{um}) known, the peak flow was calculated using Equation 4. The calculated values are given in Appendix J.

After the peak flows for the individual subwatersheds were calculated, the NRCS runoff analysis was performed for the watershed of concern as a whole. College Branch was considered the longest flow path for the watershed. Sheet and shallow concentrated flow were assumed above the headwaters of the stream. The channel segment was broken into three portions based on the channel cross-sections available; cross-sections 1, 2, and 3 were averaged for the channel north of Maple Street, cross-sections 4, 5, 6, and 7 were averaged for the channel reach between Leroy Pond Drive and Lady Razorback Road, and cross-sections 8, 9, and 10 were averaged for the reach between Lady Razorback Road and Highway 62. Pipe flow was considered for the stream section located underground. The pipe schematics map (Figure I13 in Appendix I) was utilized to determine the diameters of the pipe in this section and the lengths of each pipe size. The box-shaped pipes were modeled like rectangular channels. Depths of water were assumed as a tenth of the actual pipe depth for the box-shaped pipes. The depth of water in the round pipe was assumed as the value that led to a cross-sectional area of water equal to a tenth of the total pipe cross-sectional area. These assumptions was made due to the fact that no known base flow water surface elevations were known for the underground pipes and access to the pipes for measurements was unfeasible. The hydraulic parameters and calculated times of travel for the longest flow path are given in Table J2 of Appendix J.

The peak flows for each storm event were calculated for the watershed of concern by using the sum of the times of travel as the total time of concentration and the weighted average of the CN for the overall CN of the watershed. The calculated peak flows are given in Table J3 of Appendix J.

3.1.2 NSS Program Flood Frequency Analysis

The NSS Program flood frequency equations were used to evaluate peak flow for Fayetteville, AR, which is in Region B of the flood frequency map (see Figure 7). The set of equations given in Equation 10 were evaluated, and the area and slope values calculated in the NRCS evaluation were used. The mean basin elevations were determined by taking the average of the highest and lowest elevations for each subwatershed using the contour map for subwatersheds (Figure 10). The mean annual precipitation values were determined from the National Precipitation Atlas of the United States (USDI, 2000). The mean annual precipitation for Fayetteville was determined to be 42.5 inches. Values for each needed parameter and the calculated peak flow for the storm events for each subwatershed are given in Appendix K.

3.1.3 Gage Station Runoff Analysis

USGS Gage Station 07048480 is located on the upstream side of the box culvert under Highway 62, on the edge of campus and at the end of the reach of concern of College Branch. According to the 2011 USGS Water-Data Report for this gage station, the gage is location at 36°03’25”,-94°10’34” (NAD83), in the southwest ¼ of the southwest ¼ of Section 16, Township 16 North, Range 30 West. The drainage area for this gage is given as 0.86 square miles, and is located in the Beaver Reservoir Subbasin, which is part of the Upper White Basin. The period of record for the gage station is October 1996 to present.

HEC-SSP, as described in the literature review, is capable of analyzing gage station data downloaded from the USGS website (http://waterdata.usgs.gov/usa/nwis/uv?07048480). A study of College Branch was created in HEC-SSP and the annual peak discharge values for its gage station imported into the program. A Bulletin 17B flow frequency analysis was performed by SSP and a flow frequency plot created (Figure L1 in Appendix L). The tabular results are also given in Appendix L.

3.1.4 HEC-HMS Model

College Branch Watershed was modeled using the HEC-HMS modeling software in order to simulate peak flow in each subwatershed for each storm event. In HMS, the basin model is a representation of the orientation of the watershed. Sub-basins were created to represent the subwatersheds, with reaches connecting the sub-basins to show the direction of flow. Junctions were used to allow flow connection between subwatersheds. The basin model of the watershed of concern for College Branch Watershed is given in Figure 11.

After creating the basin model, parameters were inputted for each subwatershed. The sub-basin area in square miles was entered, as well as NRCS CN and initial abstraction values that were previously calculated. The NRCS lag time was also inputted. Lag time represents the time "between the centroid of precipitation mass and the peak flow of the resulting hydrograph" (Folmar, Miller, and Woodward, 2007). Equation 23 was used to calculate the lag time. L represents length of flow in feet, S represents maximum retention, S, in inches, and Y represents the watershed slope in percent.

$$T_{LAG} = L^{0.8} \frac{(S+1)^{0.7}}{1900\sqrt{Y}} \qquad \textit{Equation } 23$$

The calculated lag time is given in Table M1 in Appendix M along with the other aforementioned inputted parameters for HMS.

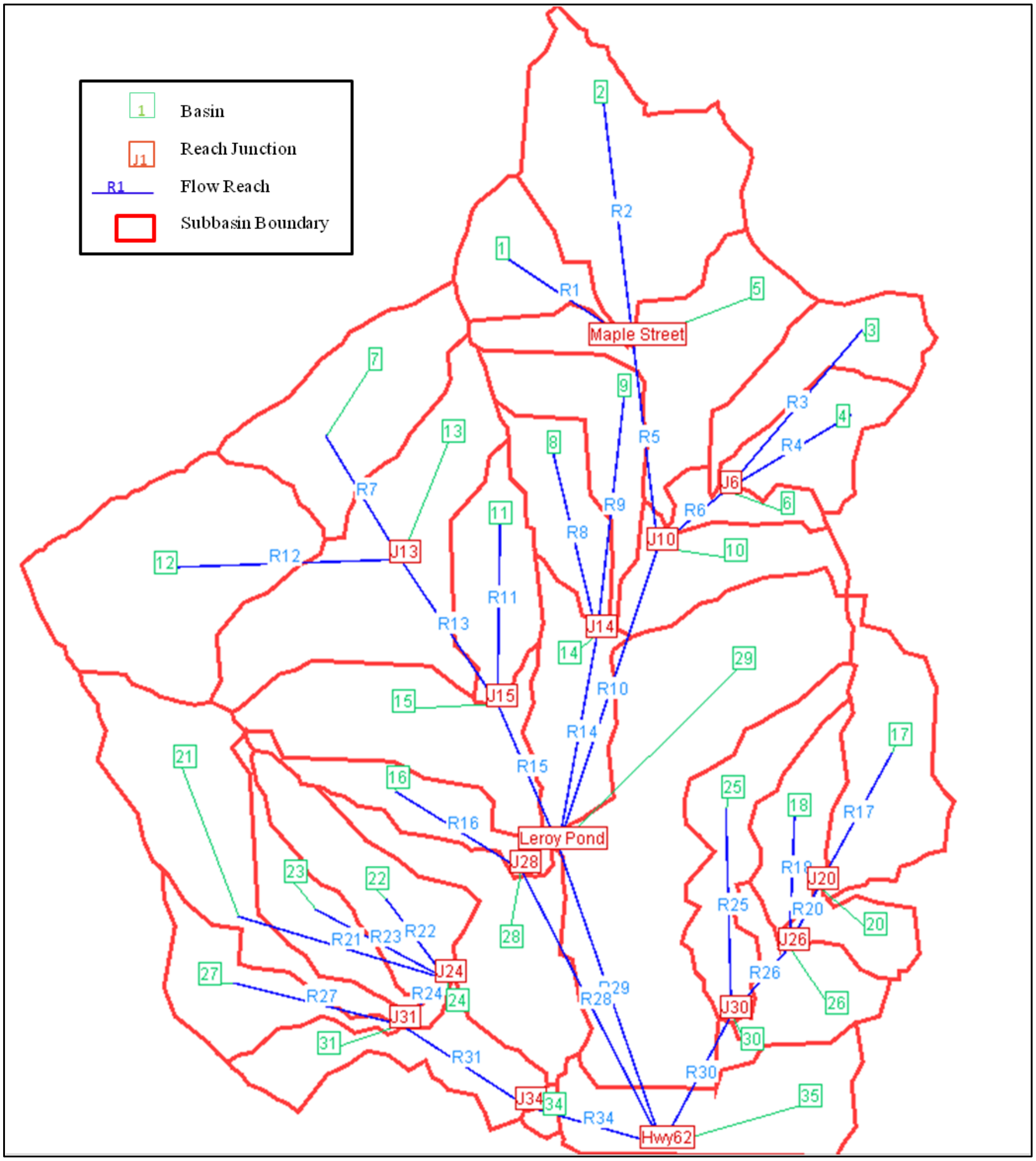

Figure 11. HEC-HMS Basin Model

Baseflow conditions for the overall watershed were also required. The inputs were given on a constant monthly basis. Data for mean monthly discharge from the USGS gage station was downloaded and inputted. This data is given in Table M2 of Appendix M.

A meteorological model for College Branch Watershed was also created in HEC-HMS. Precipitation in inches was input, along with the NRCS rainfall distribution type for Fayetteville.

In order to run the HMS model to calculate peak flow, control parameters for the runs were needed. Since the precipitation values were for 24-hour storms, a 24-hour simulation was created, running from 00:00 March 1, 2010 to 00:00 March 2, 2010. March was chosen because it has the largest baseflow. Runs were created for each storm event. Peak flow and total precipitation volume, along with time to peak, was found for each subwatershed. The output from HEC-HMS for each storm event is given in Appendix M.

3.1.5 Design Runoff Determination

After calculating the runoff values with the above methods, the results of the methods were used to calibrate a single set of runoff values for design. The NRCS method, NSS Flood frequency, and HEC-HMS modeling, allowed for peak flow calculations in each subwatershed. A comparison of the peak flow values from these methods is given in Table N1 of Appendix N.

The runoff analysis methods were used to calculate the runoff for the overall watershed of concern. Table 2 displays the values calculated from each method.

Table 2. Comparison of Runoff Analysis Results for College Branch Watershed

Method of Analysis	Peak Flow (cfs)				
	2-Year	10-Year	25-Year	50-Year	100-Year
NRCS Method	765	1233	1435	1638	1840
NSS Method	206	437	663	1213	1500
HEC-HMS Model	757	1157	1327	1498	1668

The three methods above utilized relationships between watershed parameters to determine the peak flow. The Log Pearson Type III Method utilized statistical analysis procedures. The results from the LP3 method are given below.

Table 3. Log Pearson Type III Runoff Analysis Results for College Branch Watershed

Peak Flow (cfs)				
2-Year	10-Year	25-Year	50-Year	100-Year
521	1130	1500	1798	2117

A graphical display of all four analytical methods is given in Figure 12.

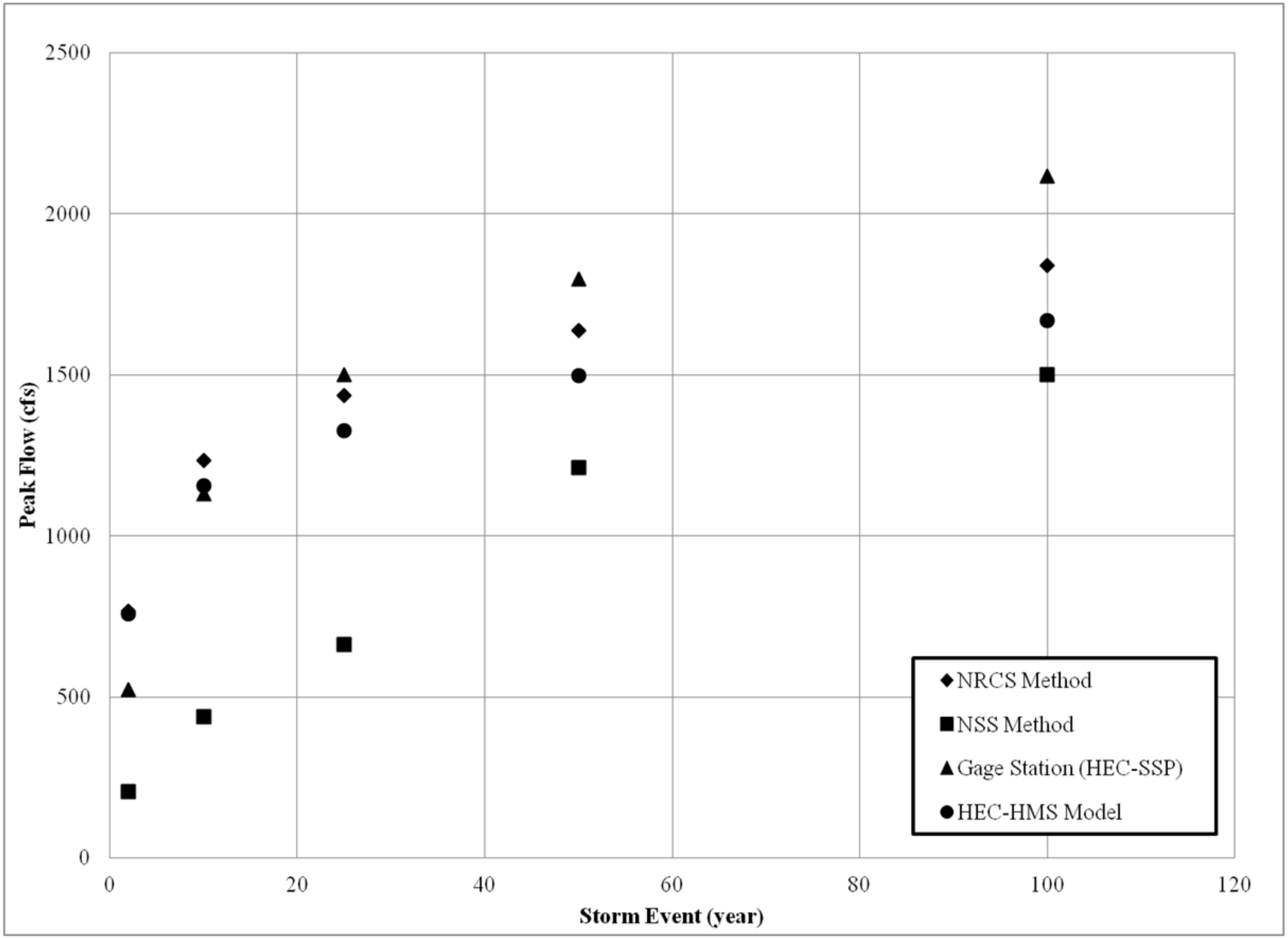

Figure 12. Comparison of Runoff Analysis Results for College Branch Watershed

The gage station data provided the highest values for peak flow for the 25, 50, and 100-year storms. The 2- and 10-year storms had peak flows of less than estimated for the NRCS and HEC-HMS methods. This could be attributed to underestimation of the time of concentration, which could have been longer for smaller storms that would have had less volume of precipitation and allowed for more natural infiltration other than direct runoff.

Since the gage station data is based on actual flows at the site, and since it has the highest estimation of peak flows for the greater storm events, the dataset was chosen for use in the design stages of the project. Higher peak flow estimations would allow for a greater safety factor in design and would better assure that the design would meet the needs of the watershed.

Peak flows for the individual subwatersheds were also determined. Since the gage station method can only provide values for the watershed as a whole, an estimation of peak flows for subwatersheds was performed knowing the ratio of subwatershed flow to total watershed flow for each storm event. The calculated percentages of flow for each subwatershed for each storm event are given in Table N2 of Appendix N.

3.2 Storage Volume Calculations

Due to the problems with flooding during storm events and erosion issues, runoff storage was of major concern. Storage of excess runoff during storms would decrease the amount of flood waters and would also decrease flow rate and velocity that cause erosion in the stream.

The storage design methods discussed in the literature review were studied. In all methods, the present peak flow values were compared with a past peak flow value, in order to determine the amount of excess runoff being created in storm events. Therefore, a past condition of the watershed was needed. Since the design would be presented to the U of A Facilities Management (FAMA) following the end of the study, multiple past conditions were studied in order to give FAMA design choices and to describe the increase of runoff due to urbanization over the years. In the design, the university could mitigate the high levels of urbanization by returning the runoff conditions to those of lesser urbanization.

The multiple conditions chosen for the study were based on either a period in time or a type of land use. The periods of time were chosen based on the availability of historical data and the level of growth of the university. Historical maps of the university area of Fayetteville were found for the years 1926 and 1962. Another time period, the pre-development time, was assumed with land use of woodlands and grass, which is consistent with undeveloped areas of land in the Fayetteville area. Four periods of time were chosen for study: predevelopment, 1926, 1962, and present.

In addition to the study involving time periods, another study involved types of land use. The present land use is highly urban, with university property that is impervious in many areas. This study considered what the state of the watershed would be if the land that is university property had instead developed similar to its surrounding area, which is mostly residential. Therefore, the watershed was considered in four conditions of land use: undeveloped (which was the same as the pre-developed condition previously discussed), residential with ½ acre lots, residential with 1/8 acre lots, and present conditions.

In order to analyze the runoff values for the conditions of study, the NRCS method was utilized. Gage station data was not available for years prior to 1996, so the best method of runoff determination was through CN analysis.

3.2.1 College Branch Watershed Conditions Determination for Time Periods

Aerial maps of College Branch Watershed were available for the years 1926 and 1962. The aerial map from 1926 was given in Appendix A. A map with the subwatersheds defined is given in Figure O1 of Appendix O. The aerial map of the watershed from 1962, provided by the U of A Facilities Management, is given in Appendix O. A map defining the stream and structures (Figure O2) and a showing the subwatersheds in 1962 area (Figure O3) also given.

Using the aerial maps, known hydrologic soil groups (HSG), and CN tables given in Appendix B, the CN for each subwatershed was determined. The land use of each subwatershed was determined from the map and then compared to the CN table for the HSG of each subwatershed. For subwatersheds with multiple land uses and HSG's, averages were taken. The land use descriptions used for each land use are given in Table 4.

Table 4. Land Use Descriptions for Subwatershed Land Uses

Land Use	Land Use Description (McCuen, 2005)
Forest	Forestland
Pasture	Pasture or Range with no Mechanical Treatment
Herbaceous	Herbaceous
Urban 1	Residential (1/4 acre lot)
Urban 3	Commercial and Business Areas

For the pre-development conditions, a hydrologic condition of "good" was used. For the 1926 and 1962 conditions, a "fair" hydrologic condition was used. The land uses and CN for each subwatershed for the four time period conditions are given in Appendix O.

After determining the land uses for each subwatershed for each time condition, the time of concentration for each was calculated. In order to do this, the flow type, flow length, Manning's n, and slope were found. Channel characteristics for the past conditions were assumed based on the aerial maps for 1926 and 1962, and by assuming that stream conditions for the undeveloped condition were similar to an undisturbed portion of College Branch. This portion is located just downstream of campus and is assumed undisturbed based on lack of urbanization and dense vegetation around the banks, and the stable state of this portion of stream.

The channel geometry for each condition was assumed as the measured geometry of the present channel, due to the fact that no other data was available to make any other assumptions. The time of concentration was then calculated in the same manner as for the present runoff analysis. Results are given in Appendix O. After calculating time of concentration, S, I_a, I_a/P, Q, q_{um}, and q_p were calculated (Appendix O) using the same methodology as described in Section 3.1.1.

The overall peak flows for the watershed for each condition were also found (Appendix O) by defining College Branch as the longest flow path and calculating the needed variables. A graphical comparison of peak flow is given in Figure 13.

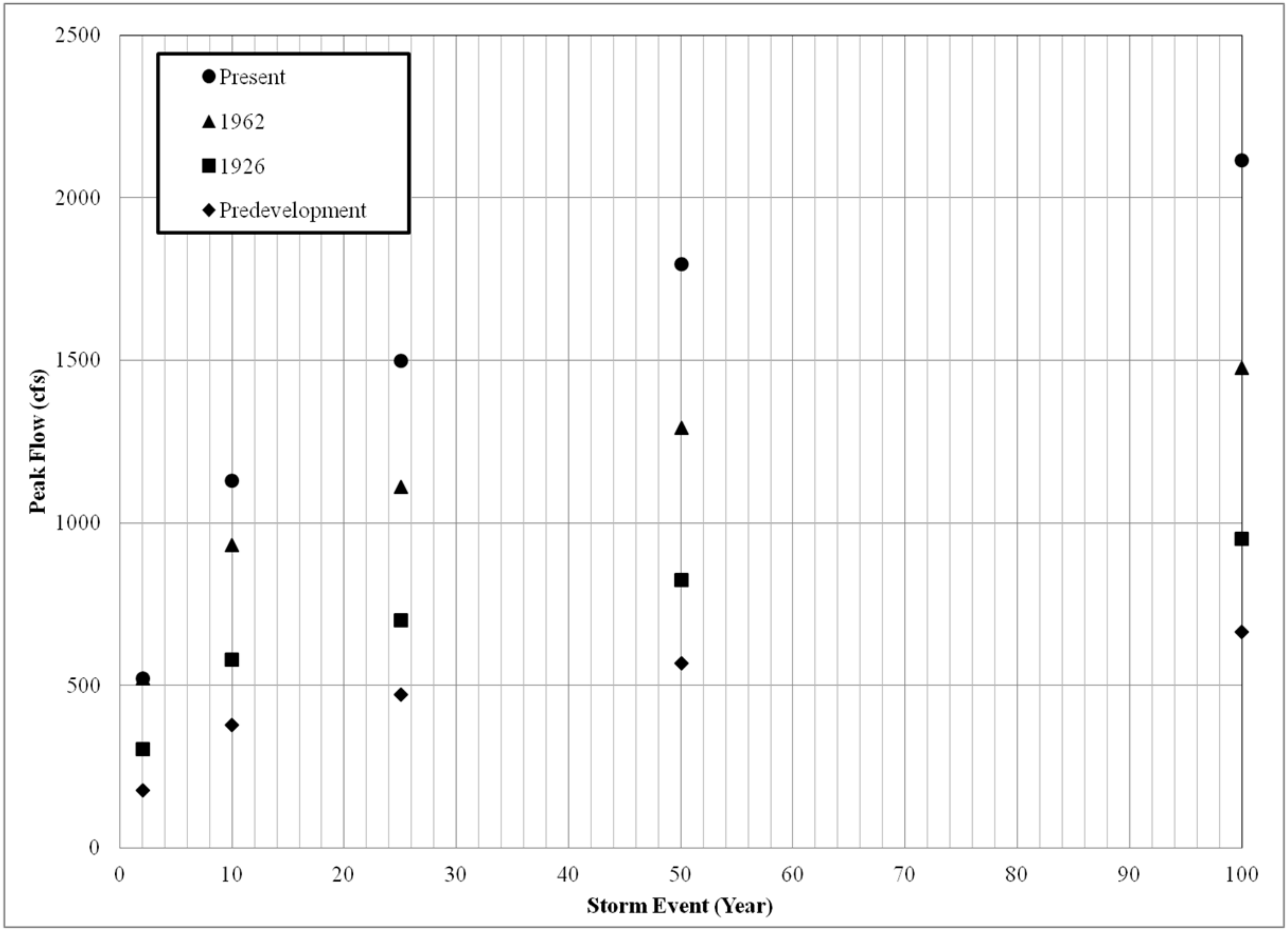

Figure 13. Comparison of Peak Flows for Development over Time in College Branch Watershed

3.2.2 College Branch Watershed Conditions Determination for Development Types

After comparing conditions based on years of development in university history, another study of runoff based on type of development was considered. The university could consider mitigation of urbanization by modifying the runoff conditions of the watershed to those of a lesser urbanized area. Due to the fact that the areas of the watershed not on university property are primarily residential, types of residential conditions were assumed for this comparison. The residential properties surrounding campus are primarily between a quarter and half acre in area. Some smaller lots are about an eighth of an acre. Due to the availability of curve numbers for residential land use, conditions of half acre lots and eighth acre lots were considered. College Branch was considered to flow along the same path as in 1926 conditions, when no part of the stream was underground. This assumption was based on the fact that the present College Branch downstream of campus flowed through a residential area and was not channelized underground for the purpose of developing above it.

The land uses for residential (1/2 acre) conditions were assumed to be similar to the surrounding area of campus in the present watershed, and so CN land use was primarily residential (1/2) acre lots and forest. The hydrologic condition of the forested areas was assumed to be “fair”. Land uses for residential (1/8 acre) conditions were assumed as residential (1/8 acre) lots. The land use of the stream was considered “Light brush and trees” for the (1/2) acre conditions and “Little to no brush” for the 1/8 acre conditions. These assumptions were based on conditions of College Branch downstream of campus, which would be similar to the conditions of the assumed residential land use conditions.

Peak flows for the overall watershed for each development condition were calculated as before, using College Branch to define the longest flow path. The tabular results are given in

Appendix O, and the results are graphically presented in Figure 14. As can be seen in the graph, increase level of land development (from undeveloped to residential conditions to urbanized) leads to an increase in peak runoff flow.

3.2.3 General Storage Method

As was described in the literature review, two general parameters, α and γ are used in many storage calculations. Both variables compare pre-development conditions with the present conditions. The purpose of implementing storage techniques is to return a watershed to a prior condition. This study considered both conditions at previous points in time and alternative development conditions. Therefore, when considering the storage amounts necessary to return the watershed to these conditions, the "pre-development" condition was considered to be the considered condition, with the present condition being that of present-day. Equations 12 and 13 were used to calculate α and γ for each condition of study, and the results are given in Table 5.

Table 5. γ and α Values for Conditions of Return for Storage

Return Condition	γ	α				
		2-Year	10-Year	25-Year	50-Year	100-Year
Undeveloped	3.80	0.341	0.335	0.326	0.317	0.314
1926	2.56	0.585	0.513	0.484	0.459	0.449
1962	1.34	1.003	0.824	0.766	0.720	0.698
Residential (1/2 ac)	3.09	0.480	0.441	0.418	0.399	0.392
Residential (1/8 ac)	1.765	0.829	0.699	0.654	0.616	0.599

In the general storage method, the volume of storage is calculated using Equations 14 and 15. Equation 14 (a and b) is dependent on whether or not α is greater or less than $2-\gamma$. For all of the storm events and time conditions in this study, α was greater than $2-\gamma$, so Equation 14b was utilized. The calculated storage volumes are given in Table 6.

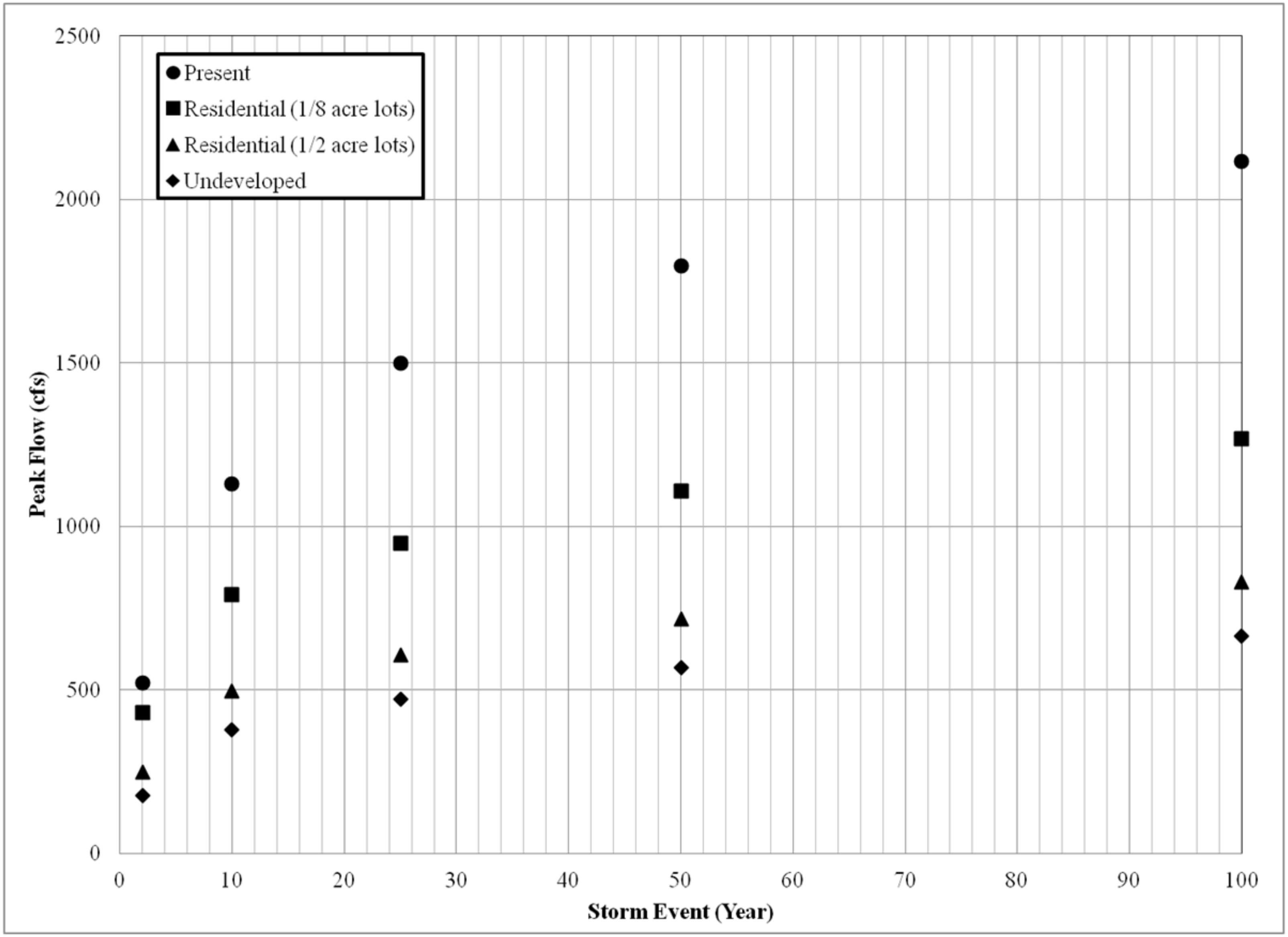

Figure 14. Comparison of Peak Flows for Types of Land Development in College Branch Watershed

Table 6. Calculated Volume of Storage for Conditions of Return using the General Method

Return Condition	Volume of Storage (acre-feet)				
	2-Year	10-Year	25-Year	50-Year	100-Year
Undeveloped	34.10	34.21	34.36	34.54	34.59
1926	25.65	27.20	27.86	28.43	28.66
1962	5.89	9.75	11.13	12.31	12.88
Residential (1/2 ac)	29.86	30.64	31.10	31.50	31.65
Residential (1/8 ac)	14.73	17.65	18.75	19.69	20.12

In Table 6, the storage volumes follow a trend of increasing with greater storm events for all conditions, except in the undeveloped condition, where the storage volume decreased slightly between the 25- and 5-year events. This was attributed to the difference in α and γ values for the undeveloped and present conditions. An analysis of the equation demonstrated that a decrease in the present-day peak flow for the 25-year event would have decreased the volume of storage enough to allow the trend of increased storage with increased storm event to continue. However, since the gage station LP3 study was used to produce the present-day peak values, the volume of storage values were accepted as calculated.

3.2.4 Loss-of-Natural-Storage Method

The Loss-of-Natural-Storage Method was also used to analyze the storage volumes for College Branch Watershed. In the method, Equation 16 from the literature review was used to calculate volume of storage in inches, with Equation 15 used to convert to acre-feet. Storage volumes calculated with the loss-of-natural-storage method are given in Table 7.

Table 7. Calculated Volume of Storage for Conditions of Return Using the Loss-of-Storage Method

Return Condition	Volume of Storage (acre-feet)				
	2-Year	10-Year	25-Year	50-Year	100-Year
Undeveloped	56.7	86.8	92.2	96.7	100.5
1926	36.83	60.11	63.29	65.90	68.08
1962	21.85	41.20	43.19	44.80	46.13
Residential (1/2 ac)	44.05	69.59	73.48	76.69	79.39
Residential (1/8 ac)	27.66	48.42	50.82	52.78	54.41

3.2.5 SCS TR-55 Method

The NRCS (formally SCS) storage method utilizes the α value calculated previously. Equation 19, which calculates ratio of storage volume to post-development runoff depth, utilizes coefficients based on rainfall distribution type. Fayetteville, AR, is located in the Type III distribution area. Equation 15 was used to convert the ratio to volume in acre-feet. Table 8 displays the calculated volumes of storage using the TR-55 method.

Table 8. Calculated Volume of Storage for Conditions of Return Using the TR-55 Method

Return Condition	Volume of Storage (acre-feet)				
	2-Year	10-Year	25-Year	50-Year	100-Year
Undeveloped	14.4	14.6	14.8	15.0	15.1
1926	10.02	11.07	11.55	11.98	12.16
1962	3.52	6.83	7.65	8.27	8.55
Residential (1/2 ac)	11.62	12.31	12.74	13.13	13.27
Residential (1/8 ac)	6.76	8.53	9.12	9.61	9.83

3.2.5 Design Volume Determination

In deciding upon the volume for storage design in College Branch Watershed, several factors were considered. Construction feasibility on the university's campus was considered in terms of space and funding. It was also important to consider the likelihood of large storm events occurring and the need for storage volume for those events.

Space was a major aspect to consider. The detention facility would need to be located on university property, an area already highly developed. Multiple acre-feet were calculated for storage volume. For better visualization, it was considered that one acre-foot of volume was equal to a basketball court filled with approximately 9 feet of water, or a football field filled with 9 inches of water. A storage facility that would hold multiple acre-feet of water would be very hard to fit on the University of Arkansas campus.

Cost was also an important consideration. In order to construct above-ground storage facilities, excavation and grading would be necessary. Underground storage facilities can be expensive because of the excavation and the required materials.

With the concerns above to consider, it was decided that it would be unfeasible to design a storage facility for a very large volume. Therefore, the storage design method chosen was the TR-55 method. In addition to calculating smaller volumes of storage, it is also a very respected and often-used method of calculation. The storage volumes calculated are presented in Table 8, and again in Figure 15 in graphical form.

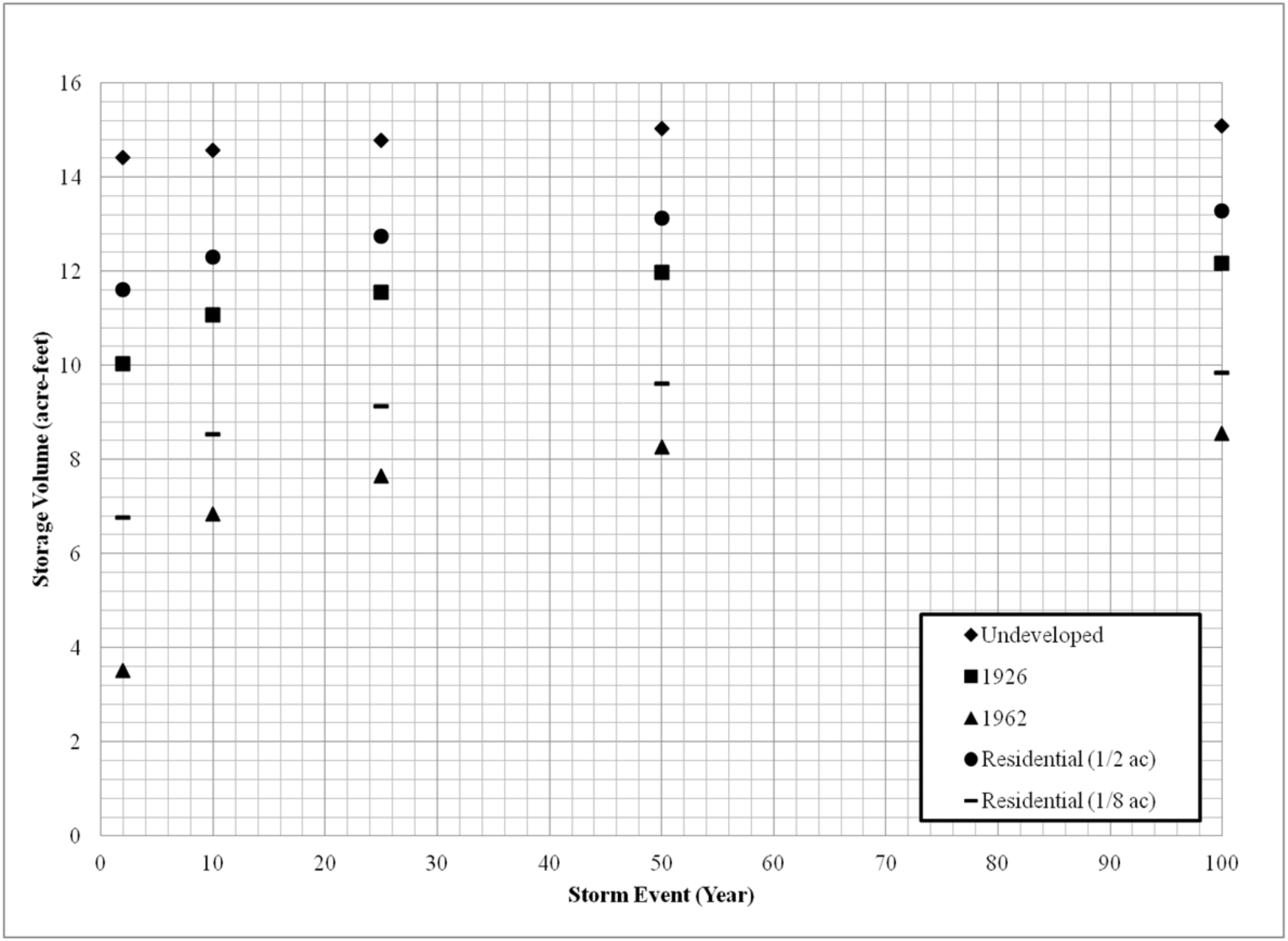

Figure 15. Comparison of Storage Volumes Calculated for Various Watershed Conditions using the TR-55 Method

3.3 Stream Rehabilitation

It was necessary to consider other aspects of the College Branch design before designing the storage facilities, as storage volume and location may be influenced by design changes to the stream.

The stream rehabilitation process began by defining rehabilitation goals. The major two problems with College Branch were flooding and erosion. Both issues stem from the excess amounts of storm runoff entering the stream during and after a storm event. Implementing runoff storage would decrease flooding issues and decrease peak flow, which is a main cause of stream bank erosion. Therefore the goal of the rehabilitation project was to create a design that would provide both flood and erosion control.

Several stream rehabilitation methodologies were considered. Though the Rosgen method was both comprehensive and well-known, the situation of College Branch on university campus prohibited much of the methodology from being used. One aspect of the Rosgen method is to analyze a reference reach for the purpose of designing the stream to its characteristics. Since College Branch is very unique in that it is highly urbanized, channelized underground, and restricted in its location, it would be unreasonable to attempt to redesign it to the specifications of a stable stream with similar properties. Also, the Rosgen method suggests creating a design with added sinuosity and stream meandering, which was not possible in most areas of College Brach due to the development of the land around it.

In considering the needs of the stream and its watershed as well as the feasibility of constructing a stream design on campus, the most attractive method for design was the two-stage channel design method. This method would allow for the active stream channel itself to remain relatively undisturbed while allowing the stream to be able to carry a larger flow and stabilizing the stream banks.

3.3.1 Two Stage Channel Design

The two stage channel design allows the stream to carry its dominant (bankfull) discharge in the main channel and allowing flood waters to flow in the secondary floodplain channel. According the National Engineering Handbook section on two stage channels, the main channel should be able to convey approximately a two-year storm event flow rate (NRCS, 2007c). The main channel side slopes can be as steep as 1:1. The floodplain channel should be three to five times wider than the main channel, with side slopes no steeper than 3:1.

It was first necessary to ensure that the current stream channel was able to convey a 2-year event. A HEC-RAS analysis was conducted on the reach of interest (from just downstream of Leroy Pond Avenue to the stream outlet at Highway 62). The GeoRAS tool in ArcGIS was used to determine the cross-section morphology at locations along the stream. Survey data taken in 2009 was also used. To best route the 2-year flow rate through the stream, flows rates at points along the stream were calculated. The peak flow of 521 cfs was known for the outlet of the stream at Highway 62, but the flow rate at the upstream end of the model was unknown. In order to calculate the flow rate, the flow direction map (Figure 10) was used to determine the watersheds that contributed to the flow of College Branch at Leroy Pond Avenue. In order to calculate the flow rate, the flow rates from each individual watershed were considered. The flow rates from contributing watersheds at each point were summed. Then, the ratio of flow at the points to the total flow (the sum of all watershed flows) was found. This ratio was multiplied by the 2-year flow from the gage station to find the flow at each point. The calculated flow is given in Table 9.

Table 9. Flow Rates along College Branch

Watershed Outlet Flow Point	Flow of Contributing Watersheds (cfs)	Ratio of flow to sum of all flows	2-Year Flow rate (cfs)
29	669	0.52	270
35	1290	1.00	521

The HEC-RAS results included a stream profile and cross-section profiles with the 2-year event water surface elevation defined. The stream profile and cross-section illustrations are given in Appendix P.

The main channel of the design two-stage channel should carry the 2-year event, so the water surface elevations given in the cross-section plots were used as the top of bank elevations for the main channel for all cross-sections.

The floodplain channel of the two-stage channel design is to be 3 to 5 times wider that the main channel. A width of three times the main channel was used in cross-section locations where the surrounding area would allow. In some locations, however, constraints including university structures or roads prohibited a floodplain width of three times the main channel. In these instances, the floodplain was widened as much as possible while still allowing for a 3:1 slope of the floodplain banks. The new cross-section stations and elevations were put into HEC-RAS and the model ran with the 2-year flow in order to verify that the main channel would carry all of the 2-year flow. The design cross-sections (surveyed cross-sections 4-9) are given in Appendix P.

The two stage channel was drawn in ArcGIS in order to determine if the design would affect any existing structures. Two main locations were affected by the design. One location that was affected was the sidewalk just east of the stream in the Gardens area. The sidewalk was built adjacent to the stream and is currently location in the stream's floodplain. Some structural damage was present in this location in 2009 and was repair by Facilities Management. Photographs of this location prior to the structural repair and after are given in Figure 16. Due to the fact that the sidewalk has been previously damaged by stream flow and the design channel extended into the present location of the sidewalk, the design included a new location for the sidewalk.

Figure 16a. Sidewalk area prior to 2009 repairs

Figure 16b. Sidewalk area after 2009 repairs

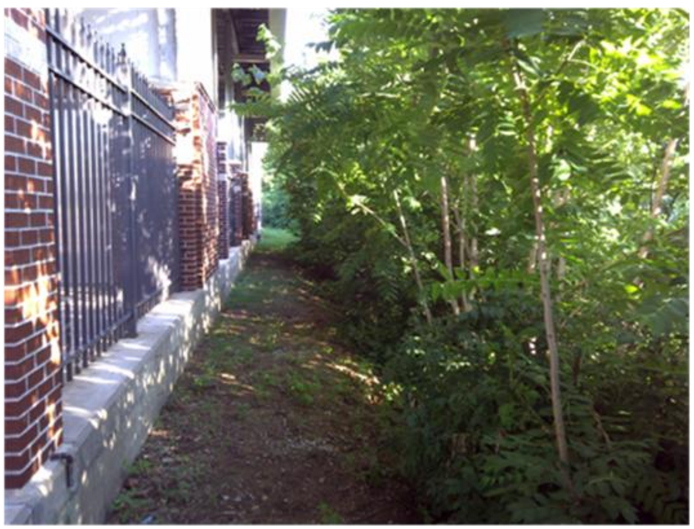

Figure 16c. East stream bank of College Branch alongside soccer field

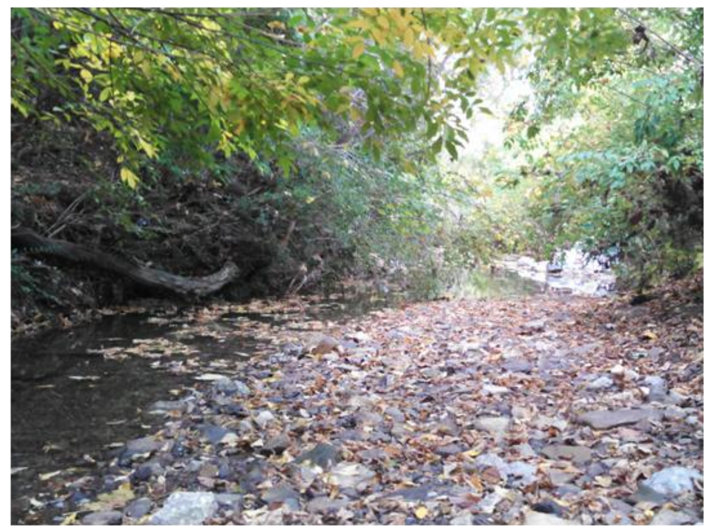

Figure 16d. Area of College Branch alongside soccer field

The design for College Branch would also affect Lot 56. In order to allow for the two stage channel in the design, it was suggested that 90 parking spaces be removed. In this area of the stream, the main channel was presently in close proximity to the Razorback soccer field bleachers and its press box. The left bank of the stream channel in this area included the press box foundation. Photographs given in Figure 16 display the present state of College Branch just west of the soccer field.

In order to prevent damage to the soccer field structures, suggestions were made in the design to move the stream in this area away from the structure. This movement of the stream would allow the floodplain at these cross-sections to be more equally distributed between the left and right banks. With the movement of the stream, the left overbank of cross-section 9 would be affected, as the design would not be constricted by the soccer field structures. The design of cross-section 9 was altered to reflect this. The updated design is given in Figure P18 of Appendix P.

In moving the stream in this section of College Branch, the sharpness of the stream's turn near Highway 62 could also be reduced by increasing the length of the turn. The stream segment that flows between the south end of the soccer field and Highway 62 could not be changed in the design due to the small distance between the two constraints. However, the angle at which the stream entered this segment was increased.

The design of the stream's location was largely based on available space. With the removal of 90 parking spaces, the new constraint to the west of the stream, Lot 56, was further away and more room was available for the two stage channel floodplain.

The two-stage channel design, including the sidewalk and stream relocations discussed previously, is depicted in an aerial view in Figure 17.

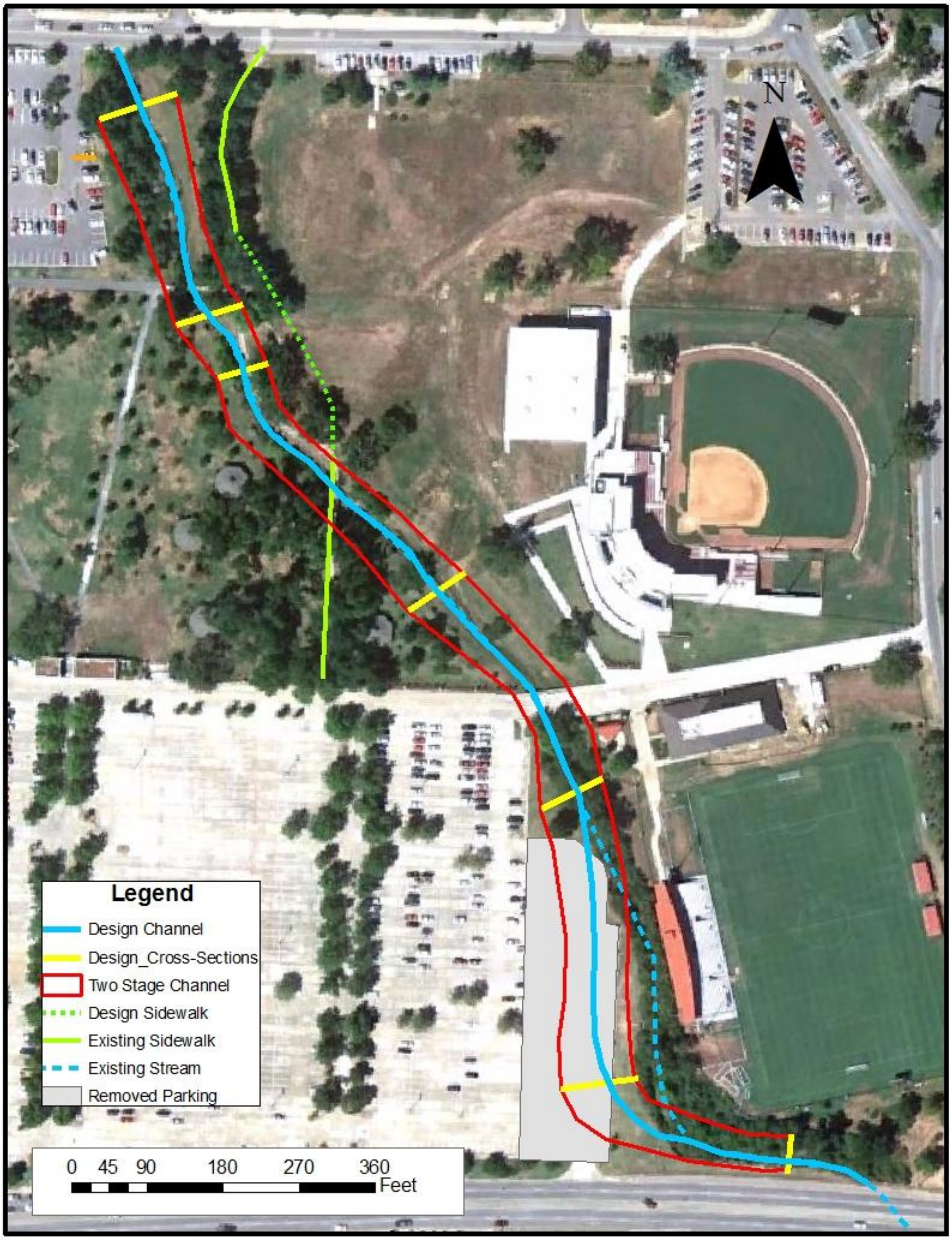

Figure 18. Aerial view of two-stage channel design for College Branch

3.3.2 Two-Stage Channel Analysis

In order to determine the effectiveness of the two-stage channel design, HEC-RAS was utilized. The flow rates for each storm event were routed through the two-stage channel geometry. HEC-RAS output is given in Appendix Q. This output also displays the calculated time of travel for each cross-section, as well as the total time of concentration for each storm event. A summary of the travel times for each storm event is given in Table 10.

Table 10. Time of Travel Summary for Study Reach for All Storm Events

Storm Event (yr)	Existing Tt (min)	Two-Stage Tt (min)	ΔTt (min)
2	5.51	6.73	1.22
10	4.88	6.27	1.40
25	5.19	6.51	1.31
50	6.28	7.08	0.81
100	5.98	8.29	2.31

As can be seen in the table, the time of concentration increased in the two-stage channel design model for each storm event. A longer time of concentration is desirable, as slower flows have a lesser ability to erode the banks.

3.3.3 Bank Protection and Stabilization

Erosion along the banks of College Branch was a visible problem at the time of study. With the two stage channel design, the new stream banks would be less steep and less likely to erode. Also, the larger channels would be able to carry a larger flow due to greater cross-sectional area. This ability would also decrease the chance of flood waters leaving the main channel and eroding the floodplains. In order to further stabilize the existing banks throughout the reach, a number of techniques were considered. As discussed previously, techniques commonly used to promote habitat were not considered as habitat restoration was not part of the design scope. The two types of streambank stabilization techniques that were applicable throughout the whole reach were rip-rap and increased riparian protection In order to prevent erosion along the design stream banks, a riparian zone along both banks of the stream was designed. A riparian zone, as discussed in the literature review, can hold soil in place and help decrease stream velocity along the banks. According to the National Engineering Handbook chapter on two-stage channels, grass cover within the flood stage benches is preferred over trees in channels that have become straightened. This is due to the fact that grass will more quickly "establish" in the absence of trees. Indigenous grasses are to be used in the flood stage area. Trees are recommended for use at the top of the two-stage channel. Dogwoods and black willow trees were chosen for the tree type due to the fact that they are commonly used in stream restoration, they are able to withstand high flows, and are both common species on Arkansas.

The riparian zone design is feasible for the length of the channel in which the two-stage design is applied. However, the most downstream segment of College Branch is very confined and therefore the two-stage channel is not possible. In this area, the channel bottom was widened but no other changes were made. Rip-rap is presently used in this location, but the current amount may not meet design criteria. The rip-rap area was redesigned using Federal Highway Administration methodology. The median stone size was determined using Equations 20 and 21 and is given in Table 11 for each storm event of concern. Velocity and depth of flow were determined using the output from the HEC-RAS analysis and the bank angle was determined from the design cross-section. The angle of repose was assumed as 41° for angular stone (FHA, 1989).

Table 11. Median rip-rap stone size for all storm events

Cross-Section	Avg. Velocity	Avg. flow depth	Bank angle with horizontal	Angle of repose	K1	Median rip-rap size	
	V_a	d_{avg}	Θ	φ		D_{50}	
	ft/s	ft	degrees	degrees		ft	in
2-Year	6.42	3.03	25	41	0.551	0.371	4.46
10-Year	8.42	3.95	25	41	0.551	0.734	8.81
25-Year	9.34	4.36	25	41	0.551	0.954	11.44
50-Year	9.97	4.64	25	41	0.551	1.124	13.49
100-Year	10.57	4.65	25	41	0.551	1.338	16.06

With the high level of erosion at the sharp turn at Highway 62, the design channel was designed to include bank protection. As discussed in the literature review, bank protection techniques include rip-rap, rootwad revetments, boulder revetments, lunkers, and a-jacks. Lunkers and a-jacks are more frequently used in areas that require fish habitat rehabilitation and bank stabilization. Revetments can offer bank stability by “keying” in either boulders or tree roots to hold in the bank materials. Lunkers require specific materials and construction, whereas revetments (especially rootwad) do not require construction. Due to the fact that habitat rehabilitation was not in the scoop of this project and project costs were a concern of the university, the rootwad revetment was chosen as the bank stability technique. The rootwad design was based upon published stream designs (Rosgen, 1993 and NRCS, 1996) in which a rootwad was “keyed” in to the banks with a boulder and a footer log underneath, which is buried perpendicular to the root wad and trunk. The boulders should be at least 1.5 times the diameter of the rootwad, the rootwad should be at least 16 inches in diameter, and the horizontal length from boulders to the end of the trunk should be 8 to 12 feet. Above the root wad, the bank is sloped back and planted with the vegetation discussed previously.

To best protect the bank from high velocities in the stream's thalweg, flow deflection was designed. Flow deflection methods include wing deflectors, log or rock vanes, and cut-off sills. For this type of turn, a log or boulder vane was chosen because the construction would occur on the same bank as the rootwad revetment, and could be incorporated into rootwad design. A log vane was chosen for design due to the fact that logs are cheaper and easier to obtain than boulders. The logs should be "keyed" in to the bank and set at an angle of 20-30 degrees (Rosgen, 1996) from the upstream bank. The angle of change of flow in the design channel is 120 degrees. Therefore, four log vanes were designed throughout the stream turn to obtain the desired angle of flow. Figure 19 displays the rootwad revetment and log vane design.

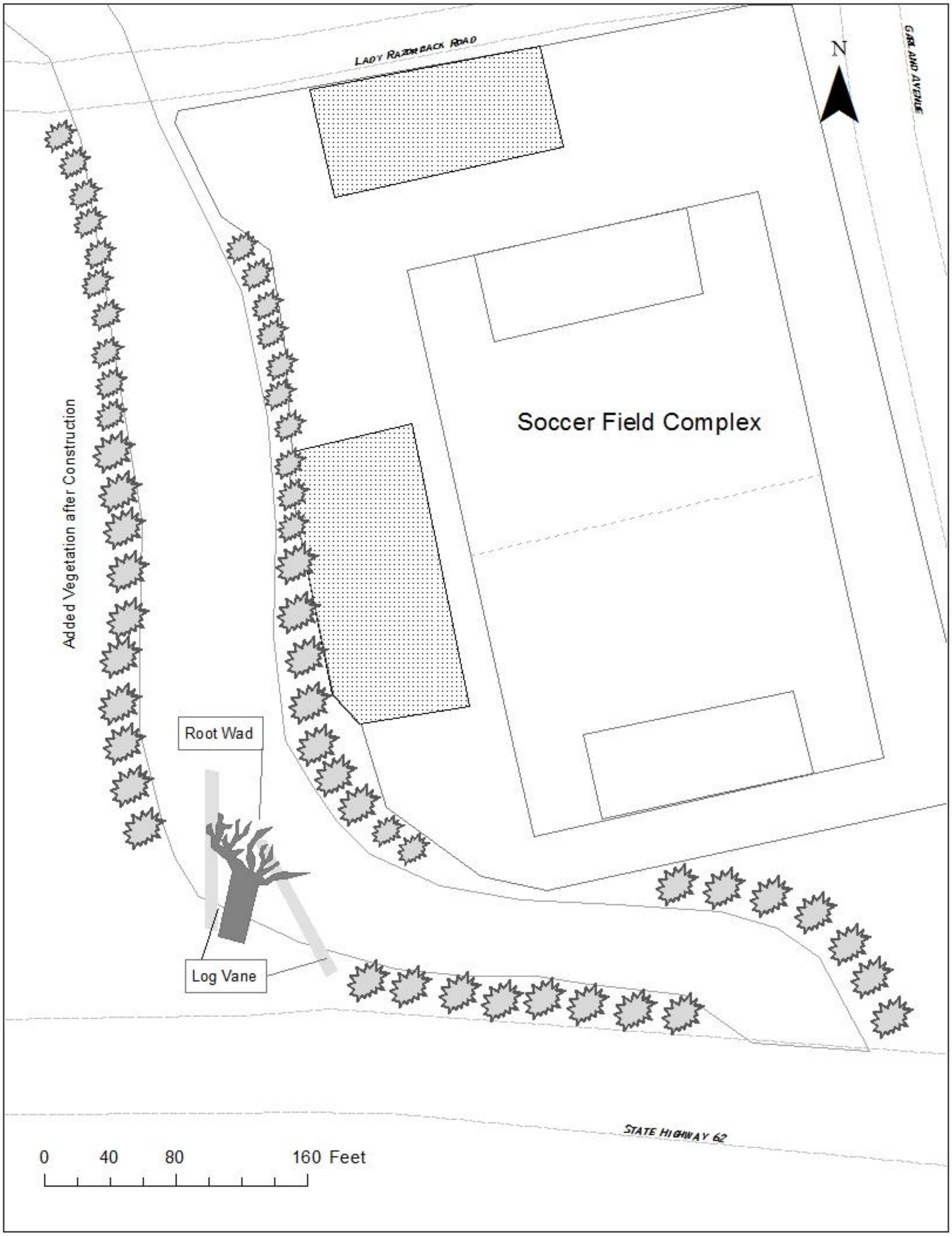

Figure 19. Log Vane and Root Wad Conceptual Design

3.3.4 Storage Design

It would be most desirous to return College Branch Watershed to as undisturbed a condition as possible, so all storage volumes of the TR-55 method were considered when designing the storage facilities in order to determine the most feasible condition of return. Multiple types of design were also considered. Conventional detention basins, underground storage, and in-stream storage were all viable types of stormwater detention possible. Multiple locations of storage were also considered so that storage facilities could be located in many areas of high runoff and so that smaller areas could be considered as possible locations.

The constraints for storage design are location and cost. Location is a major issue for College Branch because the university campus is very developed, leaving little room for detention ponds. In order to most effectively control flow rates with runoff storage, multiple locations throughout the watershed were considered for storage facility locations. By dividing the storage among many locations, the size of any one storage facility can be smaller, as it would be designed for a smaller runoff area.

In order to begin design, the possible detention facility locations were identified. One location is at the intramural recreation fields on Razorback Road. These fields provide an open area in which underground storage facilities could be installed and the intramural fields rebuilt on top. From the flow direction map given in Appendix R, it was found that subwatersheds 16, 21, 22, 23, 24, 27, 28, and 31 contribute flow to this area. The flow from these subwatersheds was used to determine the volume of storage required for this area.

Table 12.
Required Storage Volumes at Intramural Field Location for Conditions of Return

Condition of Return	Volume of storage (ac-ft)				
	2-Yr	10-Yr	25-Yr	50-Yr	100-Yr
Undeveloped	10.2	14.0	15.5	17.1	18.7
1926	6.8	9.2	10.2	11.1	12.0
1962	4.8	6.3	7.0	7.6	8.3
Half Ac	7.5	10.3	11.4	12.5	13.6
Eighth Ac	5.2	6.8	7.4	8.0	8.5

The available area at the intramural field location is 9.1 acres. In order to meet the volume of storage required for each condition of return, a variety of options exists. A detention pond taking up the entire intramural field area could be designed. If this was chosen, the depth of the pond for many conditions of return would be less than 1 foot. In addition to this option, a pond could be designed on only a portion of the field area, requiring a deeper pond to meet the volume needed for each condition. The largest volume calculated at this location is 18.7 acre-feet, which would return the peak flow in this area to an undeveloped condition for the 100-year storm event. If the entire field area was utilized for a detention pond, the depth of the pond would be 2.21 feet, assuming 3 to 1 side slopes for the pond banks. This depth is relatively small for a detention pond. A smaller surface area could be used with a larger depth to accomplish the condition of return. For example, if the detention pond was 4 feet deep, the surface area required would be 4.7 acres, only roughly half of the available area.

Another possible detention location is the courtyard to the west of Bud Walton Arena. This area is available for either above ground detention or underground storage. According to the pipe schematics for the University of Arkansas given in Appendix I, a portion of storm sewer flows under this area. This sewer pipe could be rerouted in order to allow for the detention facility, or could route some flow to the detention facility and then continue along downstream. If the sewer pipe was rerouted, the contributing subwatersheds for this facility would be 7, 11, 12, 13, and 15.

Table 13.
Required Storage Volumes at Bud Walton Arena Location for Conditions of Return

Condition of Return	Volume of storage (ac-ft)				
	2-Yr	10-Yr	25-Yr	50-Yr	100-Yr
Undeveloped	8.6	12.5	14.1	15.7	17.4
1926	5.02	6.85	7.58	8.25	8.86
1962	2.52	2.98	3.08	3.13	3.33
Half Ac	6.1	8.62	9.69	10.7	11.7
Eighth Ac	2.94	3.46	3.55	3.58	3.57

The available surface area at this location is 3.3 acres. In order to meet the largest volume requirement of 17.4 acre-feet for the undeveloped condition 100-year storm event, the pond depth required would be 6.2 feet, assuming 3 to 1 side slopes of the banks.

A number of parking lots are also possible locations for underground storage. Most notably is the parking lot adjacent to Highway 62, known as Lot 56. All subwatersheds of concern contribute flow to this location. After subtracting the volumes of storage capable at the other storage locations, the volume of storage required at Lot 56 was calculated for each storm event for each condition of return.

Table 14.
Required Storage Volumes at Lot 56 Location for Conditions of Return

Condition of Return	Volume of storage (ac-ft)				
	2-Yr	10-Yr	25-Yr	50-Yr	100-Yr
Undeveloped	33.6	45.3	50.1	54.9	59.7
1926	26.3	35.8	39.9	43.9	48.0
1962	20.7	28.8	32.2	35.5	38.8
Half Ac	29.1	39.2	43.4	47.8	52.1
Eighth Ac	23.2	32.1	35.8	39.6	43.2

The Lot 56 location would allow for a detention pond with a maximum surface area of 9.7 acres. In order to meet the volume of storage requirement for the undeveloped condition of return for the 100-year storm event, the necessary depth of the pond would be 6.2 feet with 3 to 1 side slopes. Figure 20 displays the potential detention pond locations.

Figure 20. Potential Detention Pond Locations

4. RESULTS AND DISCUSSION

4.1 Project Objectives

The purpose of this project was to develop a drainage study for College Branch on the University of Arkansas campus. Multiple types of hydrologic analyses where performed to determine the peak flows for the 2, 10, 25, 50, and 100-year storm events. No one method of analysis is accurate, but the Log-Pearson Type III analysis performed on College Branch was determined to be most accurate for this study. It utilized measured flow values from the study reach, whereas the other methods utilized assumed variables such as curve number or regional regression equations. The LP3 method was based on data collected from 1996-2009. The accuracy of this method could be increased with a larger data set if available.

The hydraulic analysis was performed in HEC-RAS. HEC-RAS is a widely used tool for stream flow analysis. The program itself allows only a certain number of iterations to keep the error in calculations to a minimum. Accuracy of the calculated values in HEC-RAS could be increased by more accurately determining hydraulic variables of the stream, including the geometry and roughness coefficients.

The implementation of the stream rehabilitation and storm water detention designs determined by this study would achieve decreased flow rates throughout the watershed and stream and decreased erosion within the stream. The flood boundaries for existing conditions, the two-stage channel design, and added storage areas are shown in Figure 21. Individual flood maps for each scenario are given in Appendix S.

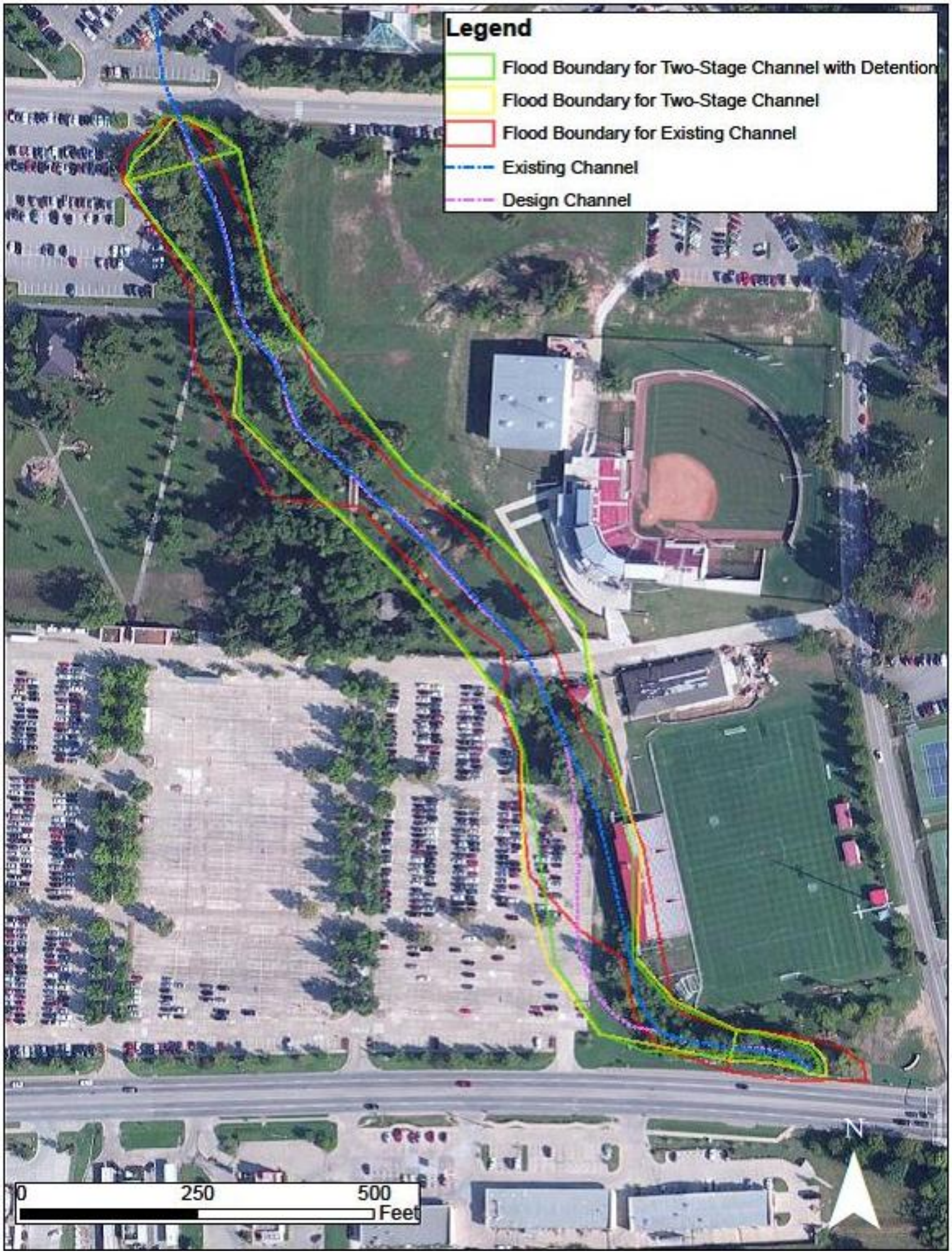

Figure 21. Flood Boundaries for Lower Reach of College Branch on Campus

With decreased erosion, aspects of the stream such as aquatic habitat and water quality could be positively impacted. Erosion can lead to increased turbidity within a stream. Turbidity can cause undesired sediment aggradation downstream, leading to undesired morphological changes of the stream channel, including stream channel relocation. High levels of turbidity can be unhealthy for aquatic life.

The drainage study given in this project provide the university with a means of better understanding the impacts of flow for various storm events for specific subwatersheds of the College Branch Watershed. Also, the study provides the university with the required changes to the watershed needed to return the flow to more desirable conditions, as well as changes to the stream necessary to hydraulically stabilize the stream. With this information, the university can make more informed decisions regarding future development and its possible impacts on the stream and hydrology of the watershed.

4.2 Project Feasibility

The suggested two-stage channel design and storage area additions are a best-case design scenario. However, both cost and location constraints would most likely render this suggested design unfeasible. Further design needs exist for consideration of the financial capabilities of the University of Arkansas, as well as the ability to dedicate land area to detention facilities. The land needed for detention is at present being used for other purposes. The intramural fields are used very frequently for curricular and extracurricular activities. Lot 56 is a primary parking facility for students as well as visitors to campus for events such as football and basketball games. Loss of parking would necessitate the creation of parking elsewhere, which would be an expensive endeavor requiring land area that is not available in the south region of campus.

The reason for determining the conditions of return for the watershed, including the time period conditions and land use conditions, was to provide the university with multiple options for returning the watershed to a more stable condition. The feasible condition of return will most likely not be to a completely undeveloped state, but that of a time or land use that provides the watershed with a less adverse storm flow situation. The hydraulic conditions of the watershed, the wildlife, and the water quality of the stream could also improve due to any level of flow rate improvement provided by the rehabilitation design.

4.3 Further Research

There is much room for further research on College Branch and its watershed. Further studies could focus on both water quality and aquatic habitat. Various methods exist for treating stormwater before entering streams. These best management practices could be further studied in order to determine potential designs for water quality improvement. The aquatic habitat conditions of the stream could also be studied. Existing locations of aquatic wildlife habitat could be identified, and methods to improve these habitats could be designed. Methods for in-stream fish habitats are common in stream restoration practices that could be coupled with stream stabilization measures.

A future study on College Branch could focus on a hard-design of the stream restoration and storage facilities conceptually designed in this study. A hard design would be required for the actual construction to take place.

Overall, this drainage study is only the precursor to many more studies needed to provide the university with a comprehensive understanding of the impacts of the university's development on the hydrology, water quality, and wildlife habitat of the watershed.

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APPENDIX A

1926 Aerial Photograph of Fayetteville, AR

1926 Aerial Photograph: Campus with Original Stream Identified

Figure A1. 1926 Aerial Photograph of Fayetteville, AR (City of Fayetteville, 2011)

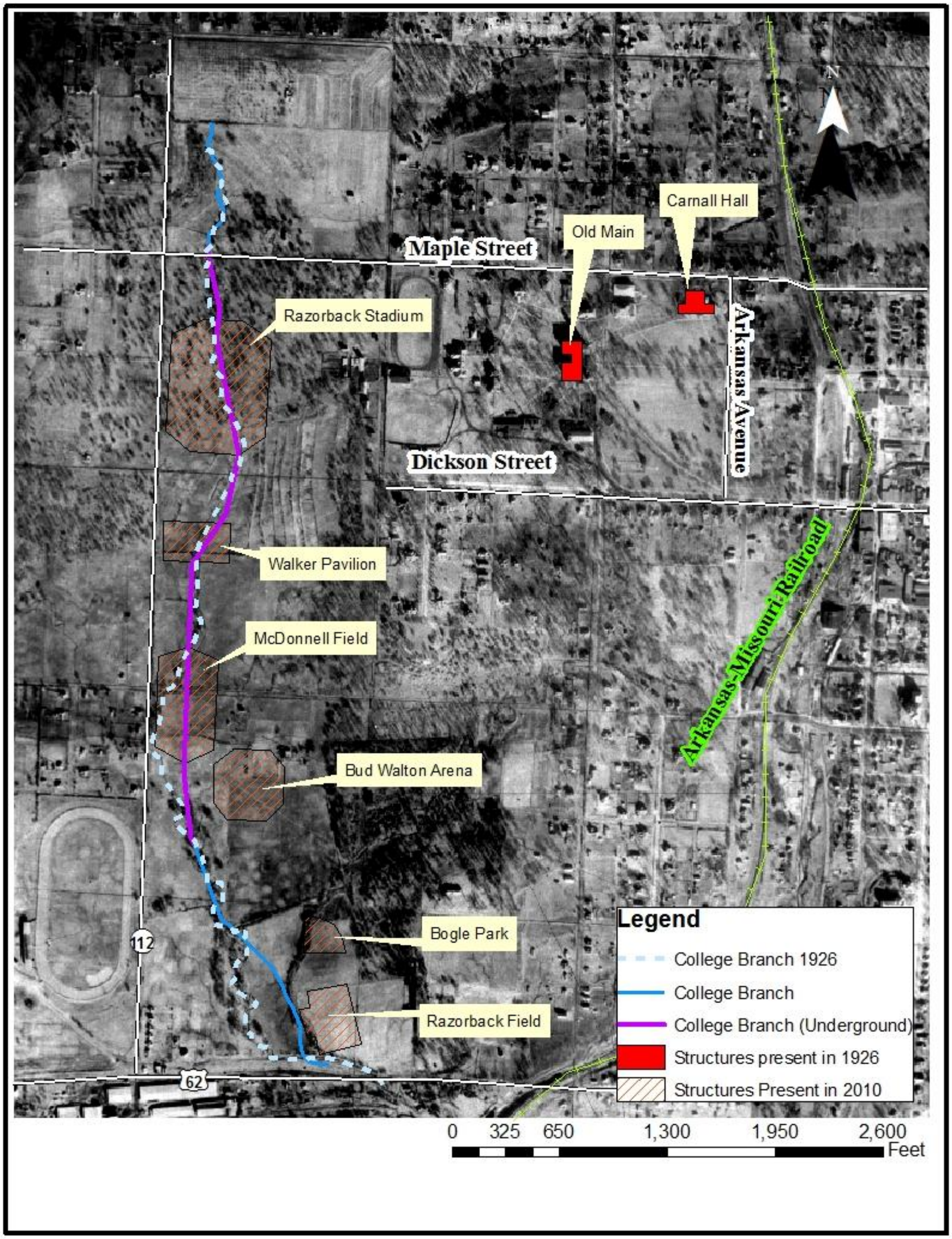

Figure A2. 1926 Aerial Map of Campus with Original Stream Identified

APPENDIX B

Rosgen River Classification Chart

Equations for Rosgen Variables

(Rosgen, 1996)

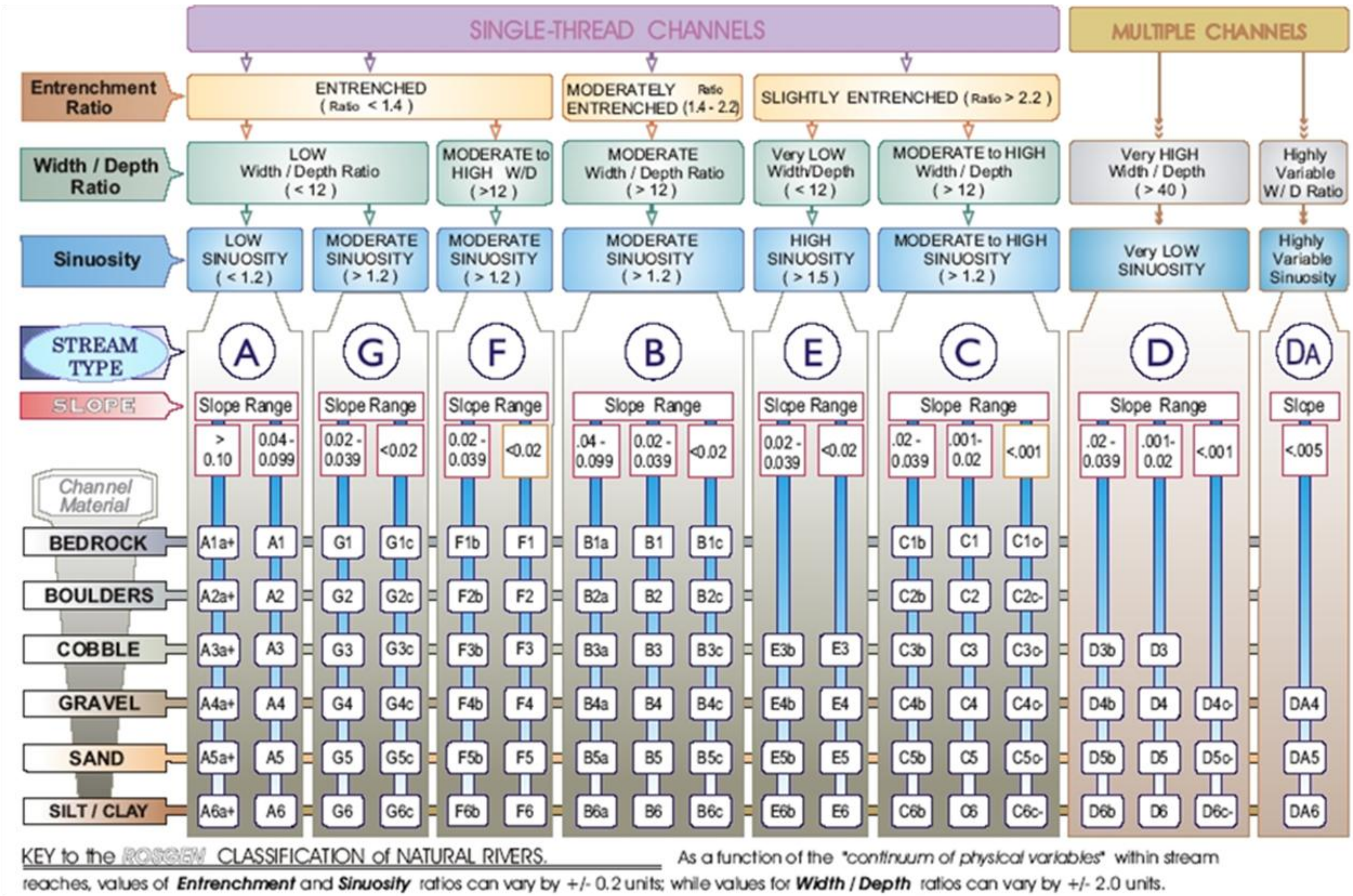

Figure B1. Classification key for natural rivers

$$Entrenchment\ Ratio = ER = \frac{width_{flood\ prone\ area}}{width_{bankfull}} \qquad Equation\ B1$$

$$Width - to - depth\ ratio = \frac{width_{bankfull}}{depth_{bankfull}} \qquad Equation\ B2$$

$$Sinuosity = k = \frac{stream\ length}{valley\ length} \qquad Equation\ B3$$

APPENDIX C

Subwatersheds of Concern Map

Contour Map of College Branch Watershed

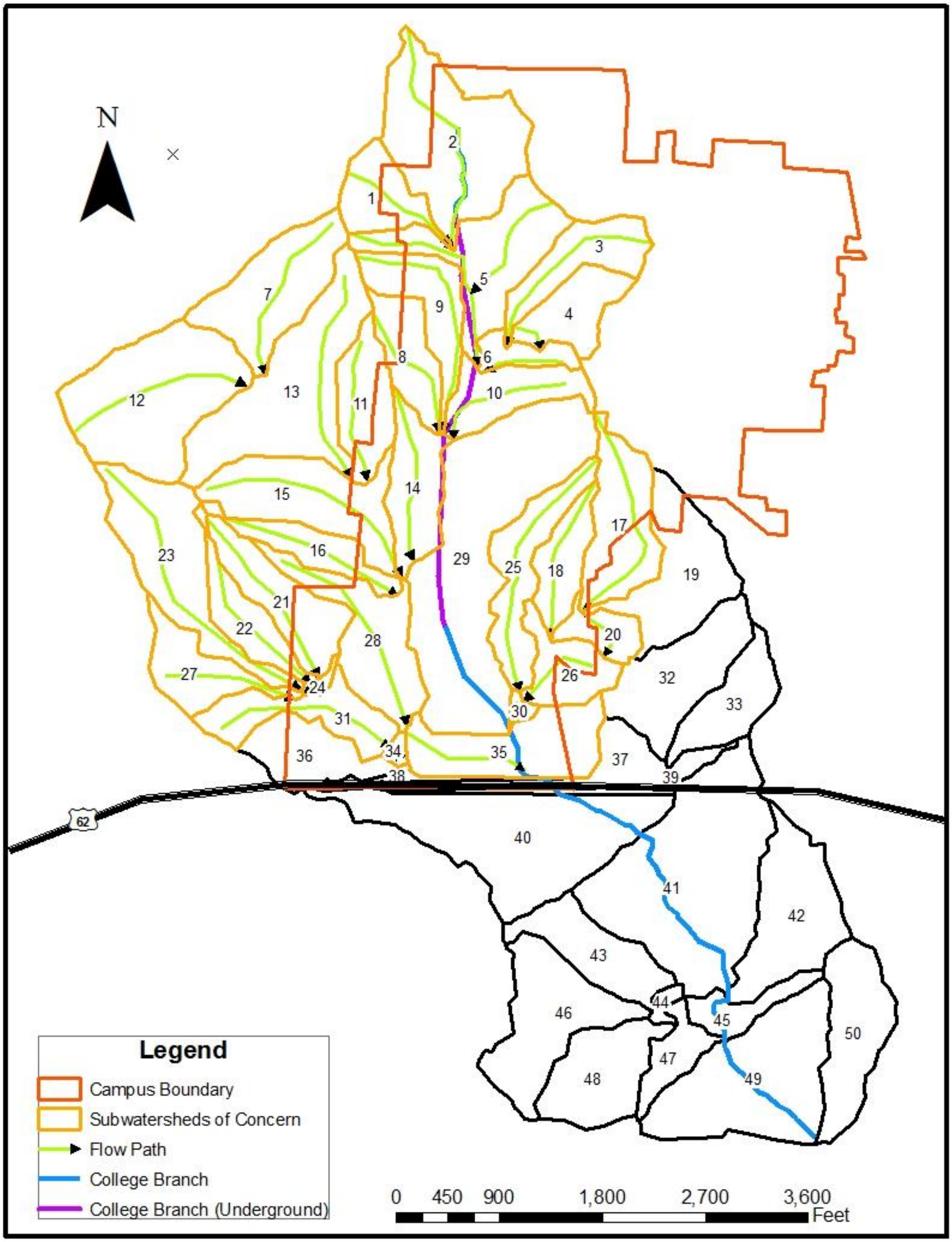

Figure C1. Subwatersheds of Concern for College Branch Watershed UA Study

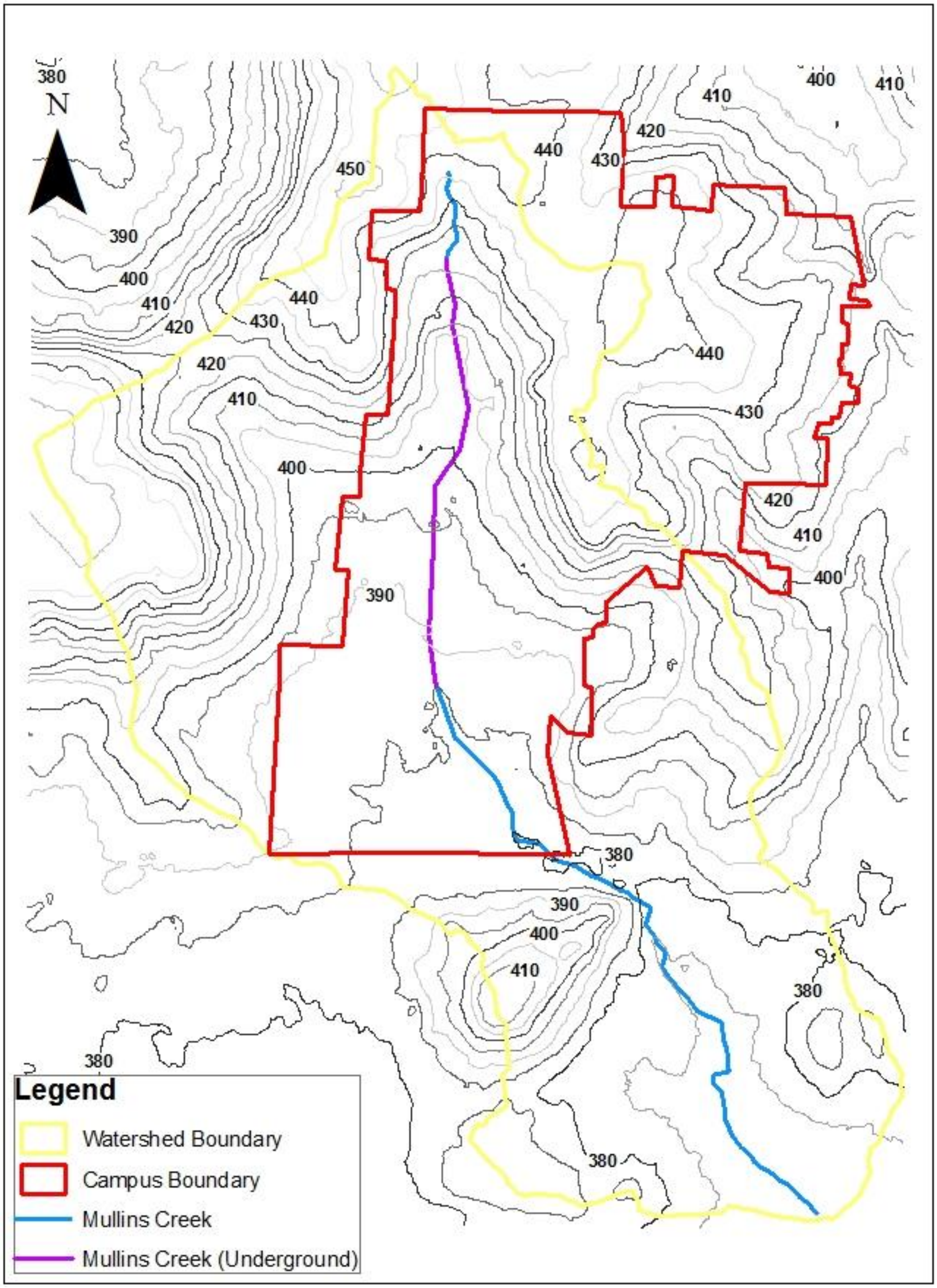

Figure C2. Contour Map of College Branch Watershed

APPENDIX D

Subwatershed Curve Numbers

Calculated S and I_a for AMCIII CN

Table D1. Curve Numbers for Subwatersheds of Concern in College Branch Watershed at AMC Values

Watershed #	CN		
	AMCI	AMCII	AMCIII
1	80	89	94
2	79	89	94
3	91	96	98
4	90	95	97
5	88	94	97
6	93	97	99
7	58	75	88
8	88	95	97
9	91	96	98
10	90	95	98
11	78	88	94
12	52	71	85
13	56	74	87
14	89	95	98
15	64	78	89
16	84	92	96
17	76	87	93
18	80	90	95
20	79	89	95
21	82	90	95
22	60	76	87
23	55	73	87
24	93	98	99
25	88	94	97
26	80	89	95
27	60	77	90
28	86	93	97
29	91	96	98
30	76	87	93
31	85	92	96
34	93	97	99
35	90	96	98

Table D2. Calculated S and I_a Values for the NRCS Method

Watershed #	S (in.)	I_a (in.)
1	0.64	0.13
2	0.64	0.13
3	0.20	0.04
4	0.31	0.06
5	0.31	0.06
6	0.10	0.02
7	1.36	0.27
8	0.31	0.06
9	0.20	0.04
10	0.20	0.04
11	0.64	0.13
12	1.76	0.35
13	1.49	0.30
14	0.20	0.04
15	1.24	0.25
16	0.42	0.08
17	0.75	0.15
18	0.53	0.11
20	0.53	0.11
22	0.53	0.11
21	1.49	0.30
23	1.49	0.30
24	0.10	0.02
25	0.31	0.06
26	0.53	0.11
27	1.11	0.22
28	0.31	0.06
29	0.20	0.04
30	0.75	0.15
31	0.42	0.08
34	0.10	0.02
35	0.20	0.04

APPENDIX E

Equation for Rainfall Intensity

Rainfall and Intensity Values for Storm Events

Intensity-Duration-Frequency (IDF) Curve for Fayetteville, AR

$$i\left(\frac{in}{hr}\right) = \frac{rainfall\ (in)}{duration\ (hour)} \qquad Equation\ E1$$

Table E1. Duration, Rainfall, and Intensity Values for Storm Events

	Duration (hr)	Rainfall (In)	I (in/hr)		Duration (hr)	Rainfall (In)	I (in/hr)
2-Year Event	0.5	1.46	2.92	50-Year Event	0.5	2.75	5.50
	1	1.77	1.77		1	3.5	3.50
	2	2.25	1.13		2	4.2	2.10
	6	2.9	0.48		6	5.6	0.93
	12	3.55	0.30		12	6.8	0.57
	24	4.1	0.17		24	8	0.33
	Duration (hr)	Rainfall (In)	I (in/hr)		Duration (hr)	Rainfall (In)	I (in/hr)
10-Year Event	0.5	2.1	4.20	100-Year Event	0.5	3.05	6.10
	1	2.7	2.70		1	3.8	3.80
	2	3.25	1.63		2	4.7	2.35
	6	4.4	0.73		6	6.2	1.03
	12	5.25	0.44		12	7.5	0.63
	24	6.2	0.26		24	8.9	0.37
	Duration (hr)	Rainfall (In)	I (in/hr)				
25-Year Event	0.5	2.42	4.84				
	1	3.1	3.10				
	2	3.75	1.88				
	6	5.1	0.85				
	12	6.1	0.51				
	24	7.1	0.30				

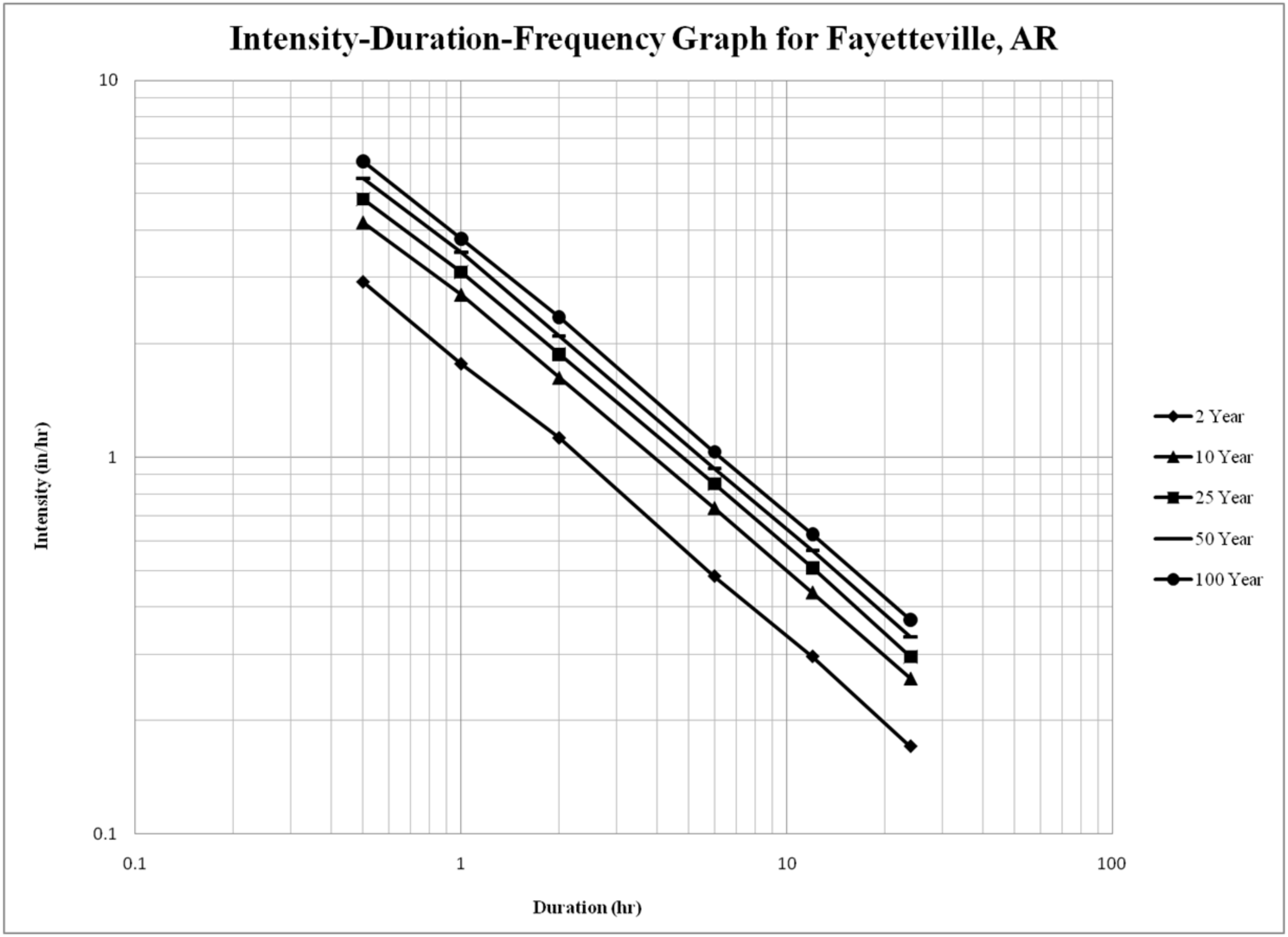

Figure E1. IDF Curve for Fayetteville, AR

APPENDIX F

Calculated Runoff Depths (Q) for each Subwatershed

Calculated I_a/P Ratios

Table F1. Calculated Runoff Depth at Storm Events

Watershed #	Q (in.)				
	2-Year	10-Year	25-Year	50-Year	100-Year
1	3.4	5.5	6.4	7.3	8.2
2	3.4	5.5	6.4	7.3	8.2
3	3.9	6.0	6.9	7.8	8.7
4	3.8	5.8	6.7	7.6	8.5
5	3.8	5.8	6.7	7.6	8.5
6	4.0	6.1	7.0	7.9	8.8
7	2.8	4.8	5.7	6.6	7.4
8	3.8	5.8	6.7	7.6	8.5
9	3.9	6.0	6.9	7.8	8.7
10	3.9	6.0	6.9	7.8	8.7
11	3.4	5.5	6.4	7.3	8.2
12	2.5	4.5	5.3	6.2	7.1
13	2.7	4.7	5.6	6.4	7.3
14	3.9	6.0	6.9	7.8	8.7
15	2.9	4.9	5.8	6.7	7.6
16	3.6	5.7	6.6	7.5	8.4
17	3.3	5.4	6.3	7.2	8.1
18	3.5	5.6	6.5	7.4	8.3
20	3.5	5.6	6.5	7.4	8.3
22	3.5	5.6	6.5	7.4	8.3
21	2.7	4.7	5.6	6.4	7.3
23	2.7	4.7	5.6	6.4	7.3
24	4.0	6.1	7.0	7.9	8.8
25	3.8	5.8	6.7	7.6	8.5
26	3.5	5.6	6.5	7.4	8.3
27	3.0	5.0	5.9	6.8	7.7
28	3.8	5.8	6.7	7.6	8.5
29	3.9	6.0	6.9	7.8	8.7
30	3.3	5.4	6.3	7.2	8.1
31	3.6	5.7	6.6	7.5	8.4
34	4.0	6.1	7.0	7.9	8.8
35	3.9	6.0	6.9	7.8	8.7

Table F2. Calculated I_a/P Values for Storm Events

Watershed #	I_a/P				
	2-Year	10-Year	25-Year	50-Year	100-Year
1	0.031	0.021	0.018	0.016	0.014
2	0.031	0.021	0.018	0.016	0.014
3	0.010	0.007	0.006	0.005	0.005
4	0.015	0.010	0.009	0.008	0.007
5	0.015	0.010	0.009	0.008	0.007
6	0.005	0.003	0.003	0.003	0.002
7	0.067	0.044	0.038	0.034	0.031
8	0.015	0.010	0.009	0.008	0.007
9	0.010	0.007	0.006	0.005	0.005
10	0.010	0.007	0.006	0.005	0.005
11	0.031	0.021	0.018	0.016	0.014
12	0.086	0.057	0.050	0.044	0.040
13	0.073	0.048	0.042	0.037	0.034
14	0.010	0.007	0.006	0.005	0.005
15	0.060	0.040	0.035	0.031	0.028
16	0.020	0.013	0.012	0.010	0.009
17	0.037	0.024	0.021	0.019	0.017
18	0.026	0.017	0.015	0.013	0.012
20	0.026	0.017	0.015	0.013	0.012
22	0.026	0.017	0.015	0.013	0.012
21	0.073	0.048	0.042	0.037	0.034
23	0.073	0.048	0.042	0.037	0.034
24	0.005	0.003	0.003	0.003	0.002
25	0.015	0.010	0.009	0.008	0.007
26	0.026	0.017	0.015	0.013	0.012
27	0.054	0.036	0.031	0.028	0.025
28	0.015	0.010	0.009	0.008	0.007
29	0.010	0.007	0.006	0.005	0.005
30	0.037	0.024	0.021	0.019	0.017
31	0.020	0.013	0.012	0.010	0.009
34	0.005	0.003	0.003	0.003	0.002
35	0.010	0.007	0.006	0.005	0.005

APPENDIX G

Land Use/Land Cover Map of College Branch Watershed

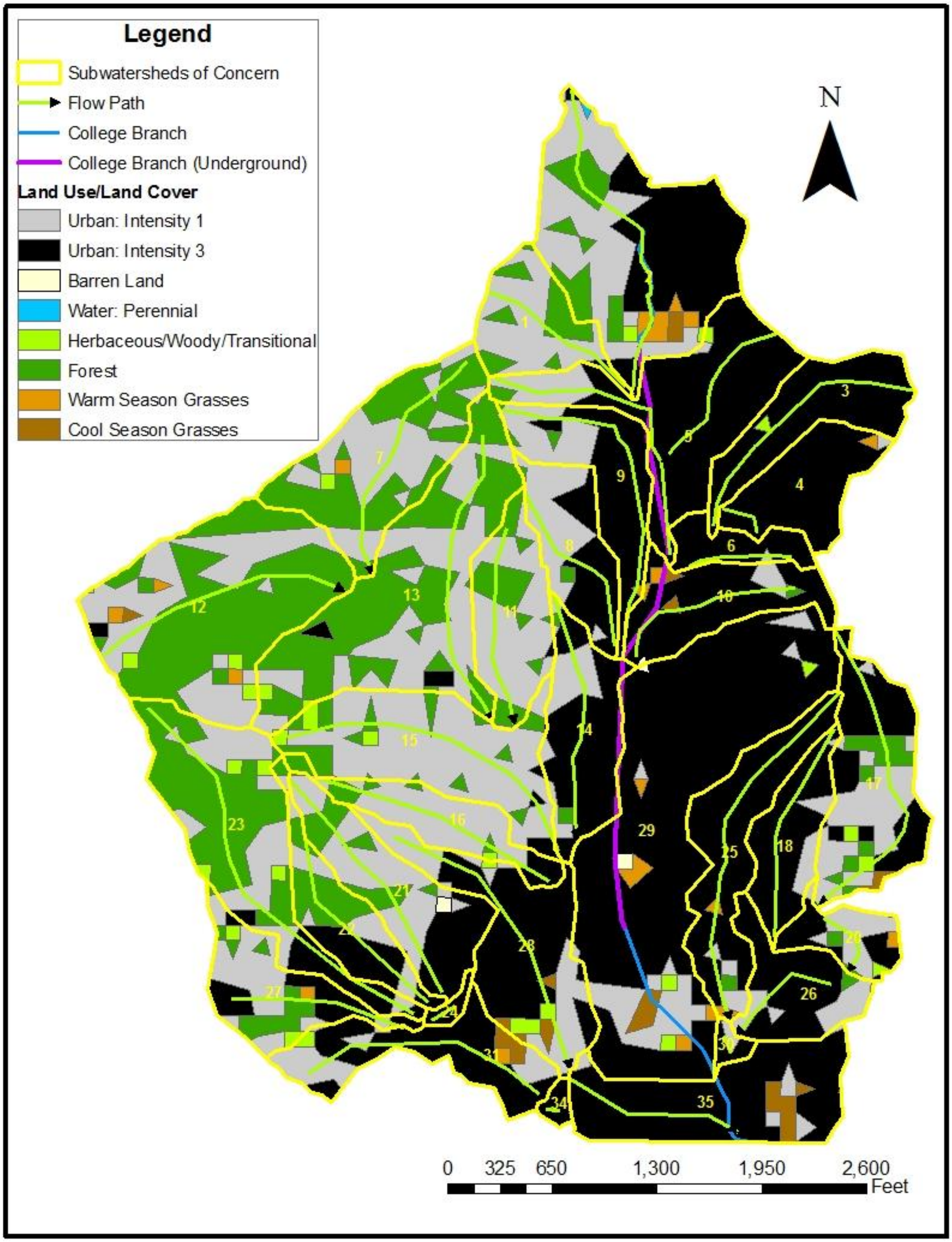

Figure G1. Land Use/Land Cover Map of College Branch Watershed with Flow Paths

APPENDIX H

Hydraulic Characteristics of Subwatersheds

Calculated Times of Concentration for Subwatersheds

Table H1. Hydraulic Parameters for Subwatershed Flow Paths and Calculated Times of Concentration

Watershed #	Type(s) of Flow	Land Use/Land Cover	Flow Length (ft)	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	Urban: Intensity 1	300	0.1	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21
	Shallow Concentrated	Unpaved	825	0.1	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.80	0.08
2	Sheet	Urban: Intensity 1	300	0.1	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	Unpaved/Paved	680	0.25	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.26	0.08
	Channel	Some grass, weeds, little or no brush	806	0.03	0.019	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	4.79	0.05
	Pipe	Concrete Pipe	70	0.011	0.008	4.1	3' by 3'	3' by 3'	N/A	N/A	3.00	5.00	0.60	8.58	0.002
3	Pipe	Concrete Pipe	1800	0.011	0.017	4.1	0.7	0.3	0.1	1.59	0.03	0.53	0.06	2.78	0.18
4	Pipe	Concrete Pipe	930	0.011	0.015	4.1	1.25	1.25	0.1	0.81	0.07	1.01	0.07	2.71	0.10
5	Pipe	Concrete Pipe	1100	0.011	0.018	4.1	1	1	0.1	1.29	0.04	0.64	0.06	2.91	0.11
6	Sheet	Urban: Intensity 1	300	0.1	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.17
	Shallow Concentrated	Unpaved/Paved	400	0.25	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.08	0.03
	Pipe	Concrete Pipe	160	0.011	0.006	4.1	4	2	0.5	1.45	0.91	2.89	0.31	4.94	0.01
7	Sheet	Forest	300	0.4	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.67
	Shallow Concentrated	Unpaved	1170	0.25	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.66	0.12
8	Sheet	Urban: Intensity 1	300	0.1	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21
	Shallow Concentrated	Unpaved/Paved	460	0.05	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.31	0.04
	Pipe	Concrete Pipe	490	0.011	0.010	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	4.38	0.03
9	Sheet	Urban: Intensity 1	300	0.1	0.042	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19
	Shallow Concentrated	Unpaved/Paved	410	0.05	0.042	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.75	0.03
	Pipe	Concrete Pipe	350	0.011	0.014	4.1	1	0.5	0.5	3.14	0.39	1.57	0.25	6.42	0.02
10	Pipe	Concrete Pipe	805	0.011	0.009	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	4.05	0.06
11	Sheet	Urban: Intensity 1/Forest	300	0.25	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	Unpaved	1220	0.25	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.62	0.13
12	Sheet	Urban: Intensity 1	300	0.1	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.25
	Shallow Concentrated	Unpaved	1350	0.4	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.16
13	Sheet	Urban: Intensity 1/Forest	300	0.25	0.022	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.50
	Shallow Concentrated	Unpaved	1925	0.25	0.022	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.22
14	Pipe	Concrete Pipe	940	0.011	0.003	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	2.45	0.11
15	Sheet	Urban: Intensity 1/Forest	300	0.25	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.48
	Shallow Concentrated	Unpaved	1945	0.1	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.53	0.21
16	Sheet	Forest	300	0.4	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	Unpaved	1900	0.1	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.62	0.20
17	Sheet	Urban: Intensity 1	300	0.1	0.029	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.22
	Shallow Concentrated	Unpaved/Paved	1380	0.1	0.029	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.11	0.12
18	Sheet	Urban: Intensity 3	300	0.1	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21
	Shallow Concentrated	Unpaved/Paved	1135	0.1	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.16	0.10
20	Sheet	Urban: Intensity 1	300	0.1	0.031	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21
	Shallow Concentrated	Unpaved/Paved	320	0.1	0.031	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.19	0.03

21	Sheet	Urban: Intensity 1	300	0.1	0.048	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.18
	Shallow Concentrated	Unpaved/Paved	840	0.25	0.048	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4.00	0.06
	Channel	Roadside channel, short grass	370	0.02	0.005	4.1	N/A	N/A	N/A	N/A	1.00	2.80	0.36	2.76	0.04
22	Sheet	Urban: Intensity 1/Forest	300	0.25	0.035	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.42
	Shallow Concentrated	Unpaved/Paved	1350	0.15	0.035	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.42	0.11
	Channel	Roadside channel, short grass	150	0.02	0.007	4.1	N/A	N/A	N/A	N/A	1.00	2.80	0.36	3.06	0.01
23	Sheet	Forest	300	0.4	0.022	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.73
	Shallow Concentrated	Unpaved/Paved	2390	0.15	0.022	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.24
	Channel	Roadside channel, short grass	90	0.02	0.011	4.1	N/A	N/A	N/A	N/A	1.00	2.80	0.36	3.95	0.01
24	Sheet	Urban: Intensity 3	50	0.011	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.02
	Shallow Concentrated	Paved	80	0.011	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.26	0.02
25	Sheet	Urban: Intensity 3	300	0.011	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.04
	Shallow Concentrated	Paved	850	0.011	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.55	0.07
	Pipe	Concrete Pipe	250	0.011	0.008	4.1	2	1	0.5	2.09	0.61	2.09	0.29	5.35	0.01
26	Sheet	Urban: Intensity 3	300	0.011	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.04
	Shallow Concentrated	Unpaved/Paved	540	0.011	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.05
27	Sheet	Urban: Intensity 1/3	300	0.05	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.14
	Shallow Concentrated	Unpaved/Paved	1400	0.12	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.15
28	Sheet	Urban: Intensity 1	300	0.1	0.041	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19
	Shallow Concentrated	Unpaved/Paved	450	0.011	0.041	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.71	0.03
	Channel	Roadside channel, short grass	1700	0.02	0.003	4.1	N/A	N/A	N/A	N/A	4.00	5.80	0.69	3.15	0.15
29	Pipe	Concrete Pipe	2905	0.011	0.009	4.1	3.5	1.75	0.5	1.55	0.84	2.71	0.31	5.76	0.14
	Channel	Some grass, weeds, little or no brush	1120	0.03	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.79	0.17
30	Pipe	Concrete Pipe	240	0.011	0.004	4.1	1	0.5	0.1	1.29	0.04	0.64	0.06	1.39	0.05
31	Sheet	Urban: Intensity 1/3	300	0.05	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.16
	Shallow Concentrated	Unpaved/Paved	530	0.015	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.06
	Channel	Roadside channel, short grass	1020	0.02	0.003	4.1	N/A	N/A	N/A	N/A	3.00	4.80	0.63	2.95	0.10
34	Channel	Roadside channel, short grass	276	0.02	0.004	4.1	N/A	N/A	N/A	N/A	1.00	2.80	0.36	2.26	0.03
35	Pipe	Concrete Pipe	920	0.0011	0.002	4.1	5	2.5	0.50	1.29	1.02	3.22	0.32	29.40	0.009
	Channel	Some grass, weeds, some brush	590	0.04	0.005	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	1.31	0.12

APPENDIX I

2009 Survey Cross-Section Maps

2009 Survey Cross-Sections

University of Arkansas Underground Pipe Schematics

Figure I1. Map of Upper Segment of College Branch with Surveyed Cross-Section Locations

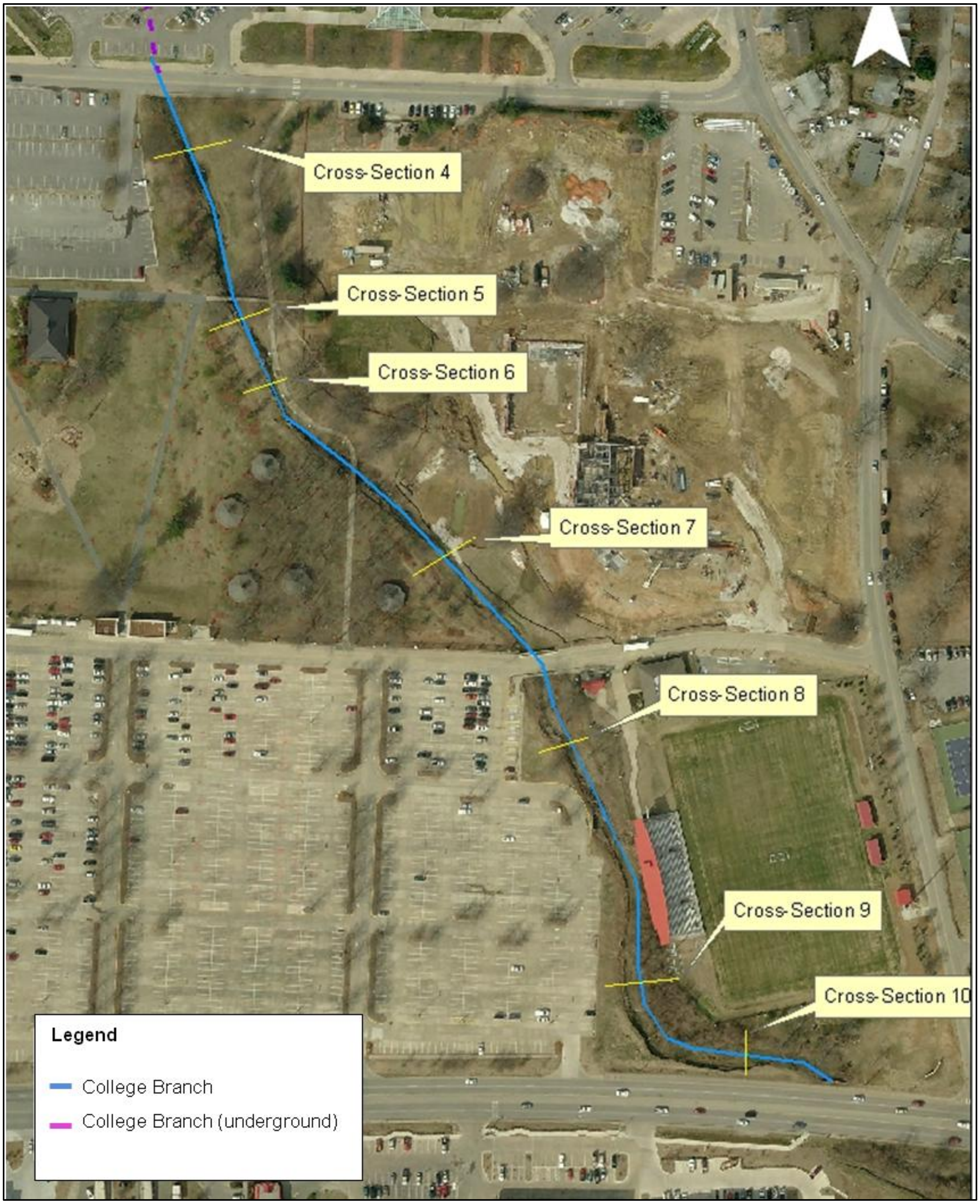

Figure I2. Map of Lower Segment of College Branch with Surveyed Cross-Section Locations

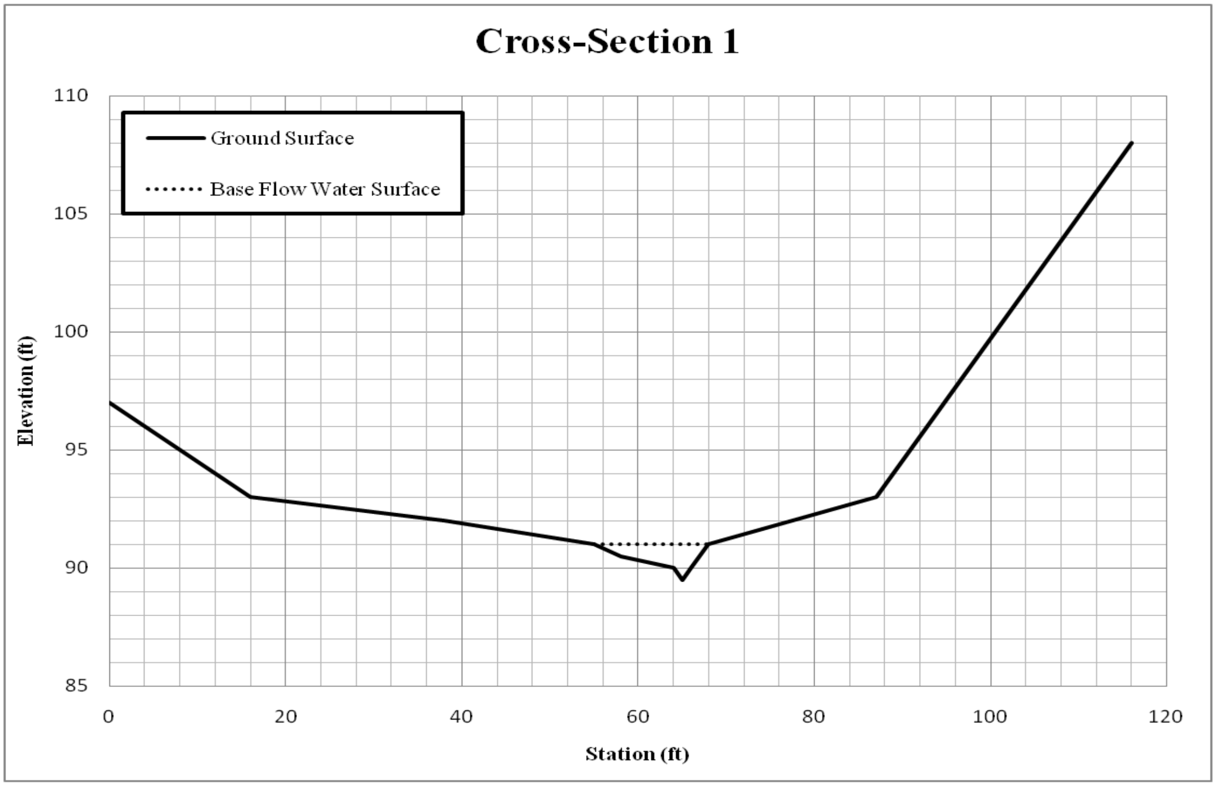

Figure I3. Cross-Section 1

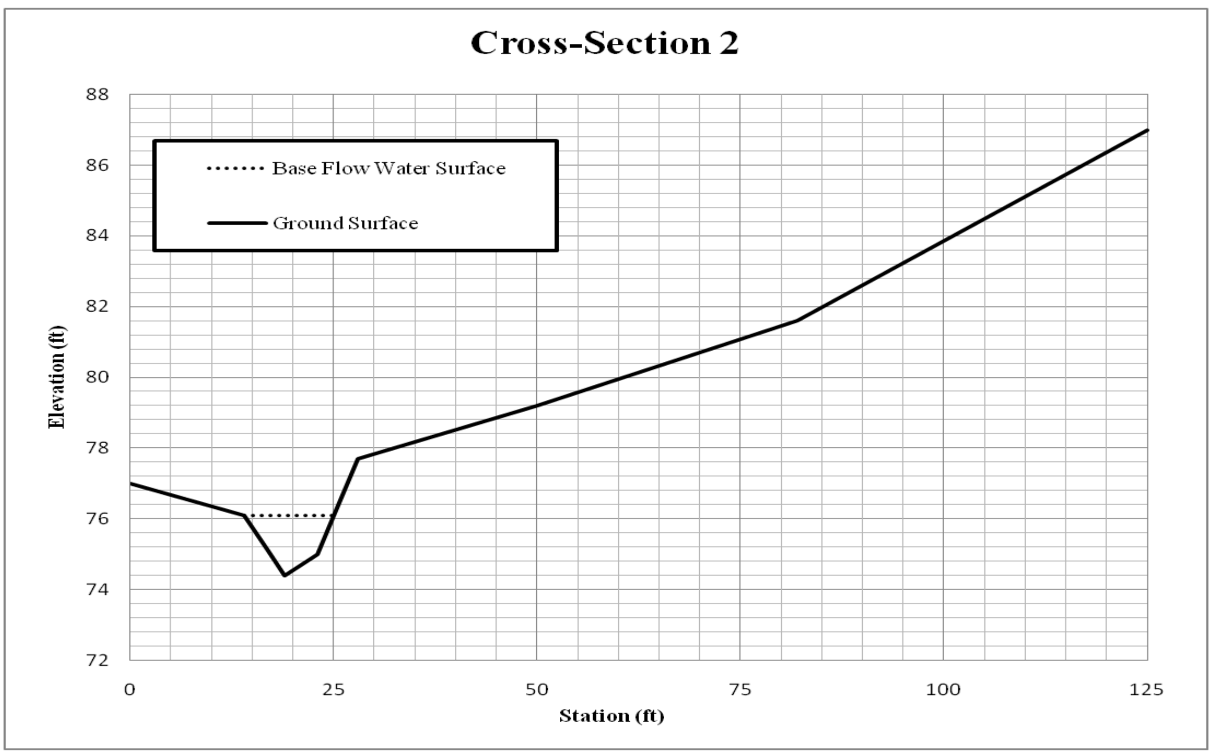

Figure I4. Cross-Section 2

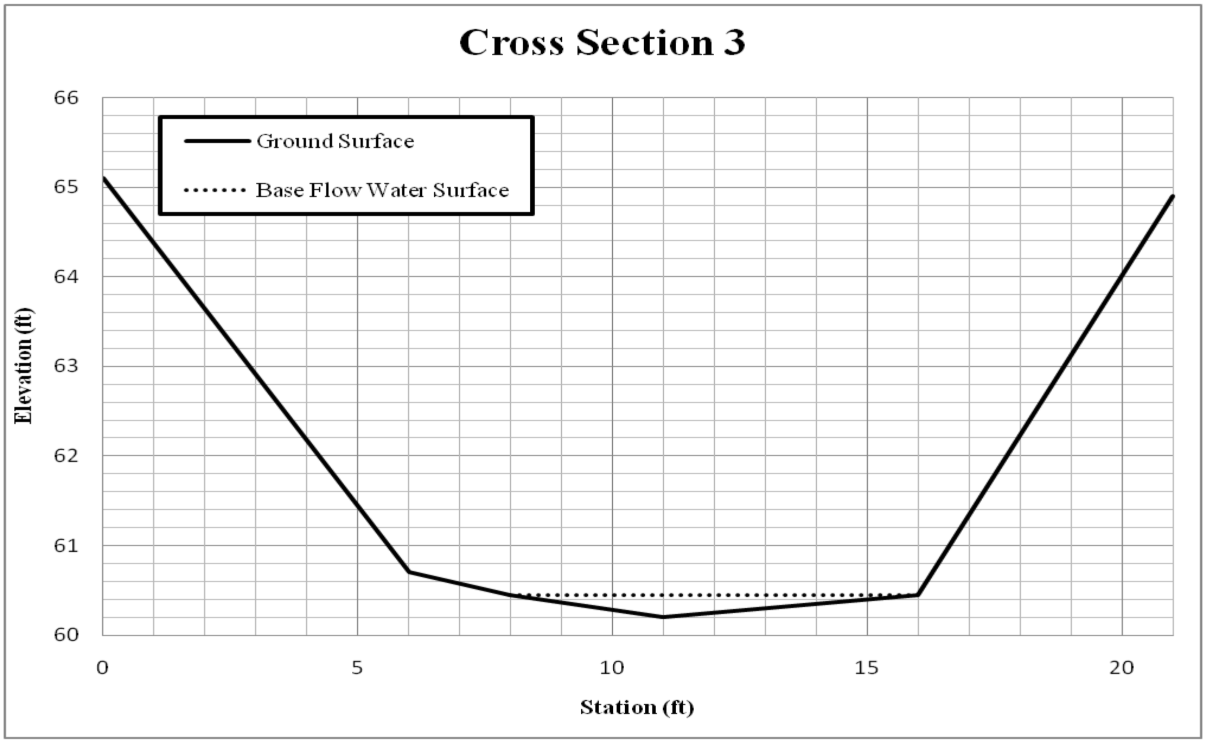

Figure I5. Cross-Section 3

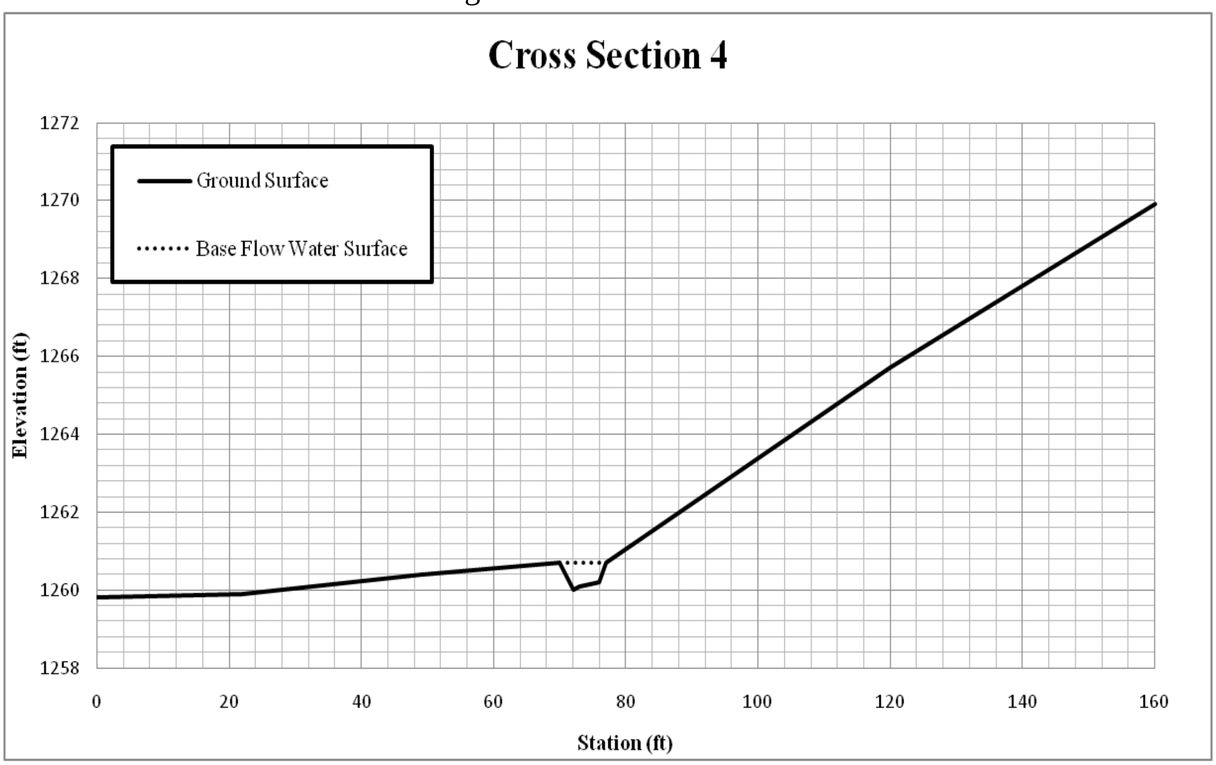

Figure I6. Cross-Section 4

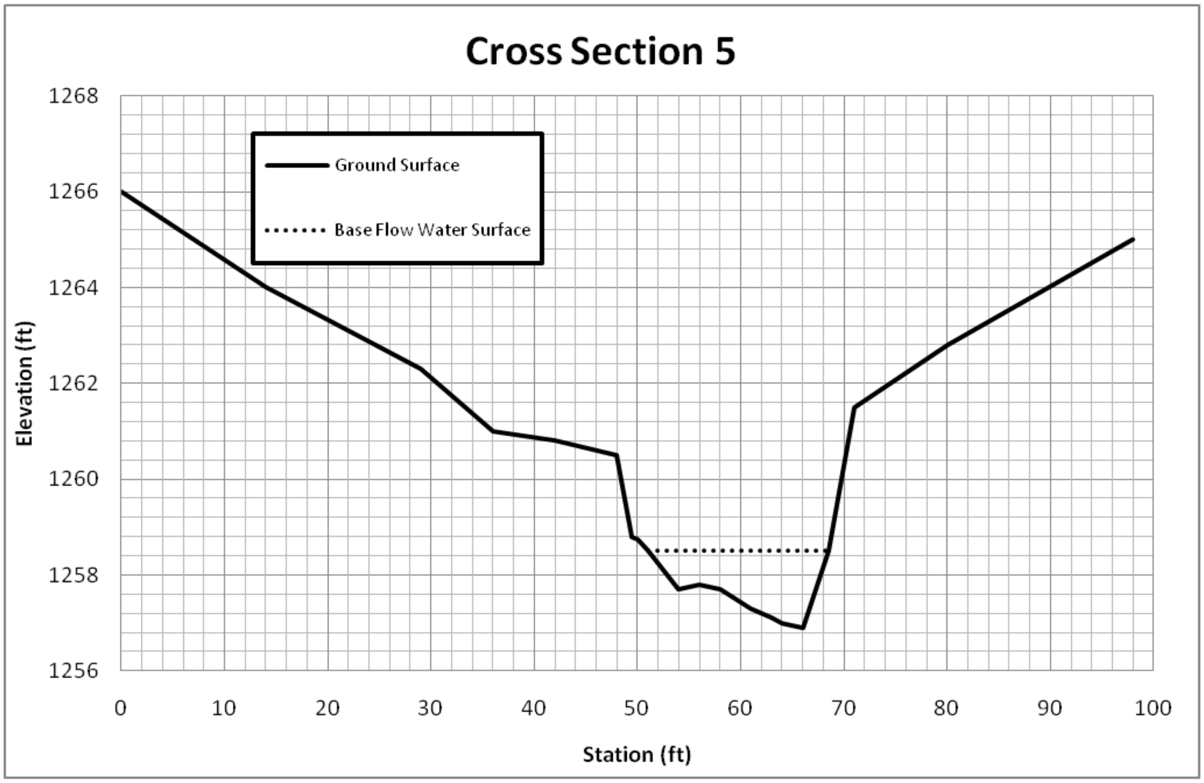

Figure I7. Cross-Section 5

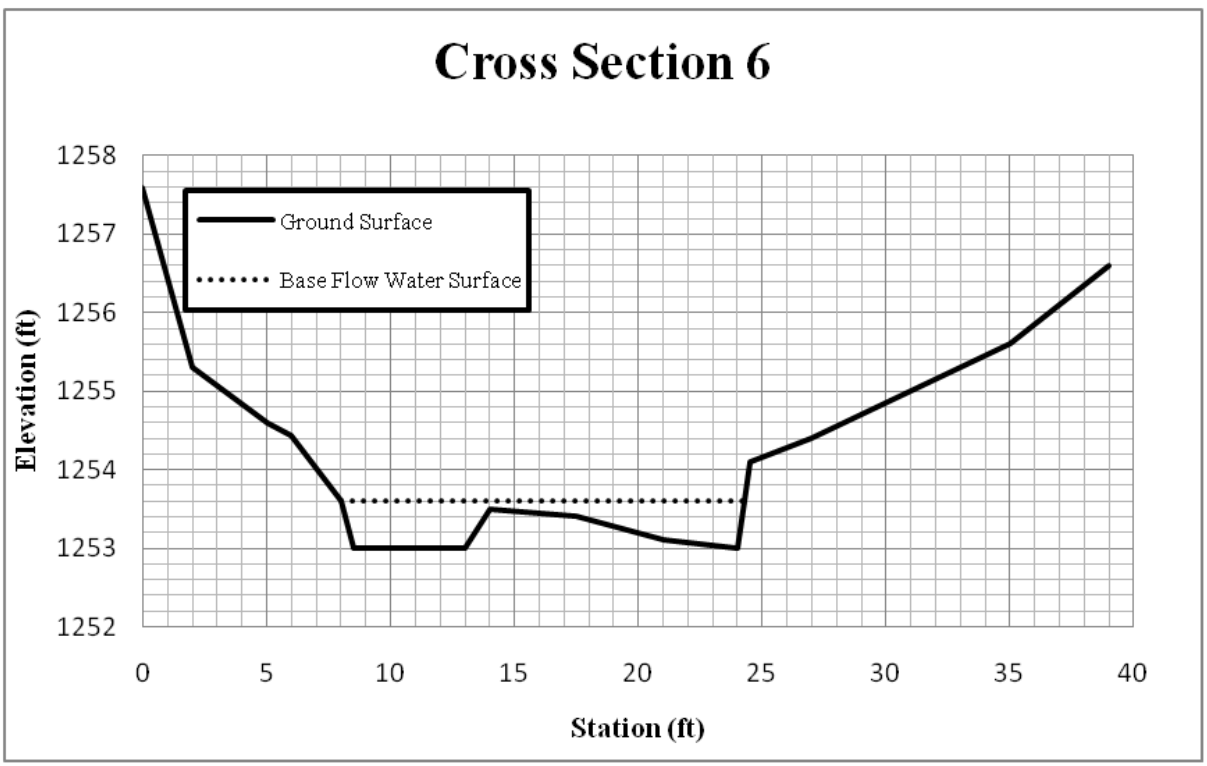

Figure I8. Cross-Section 6

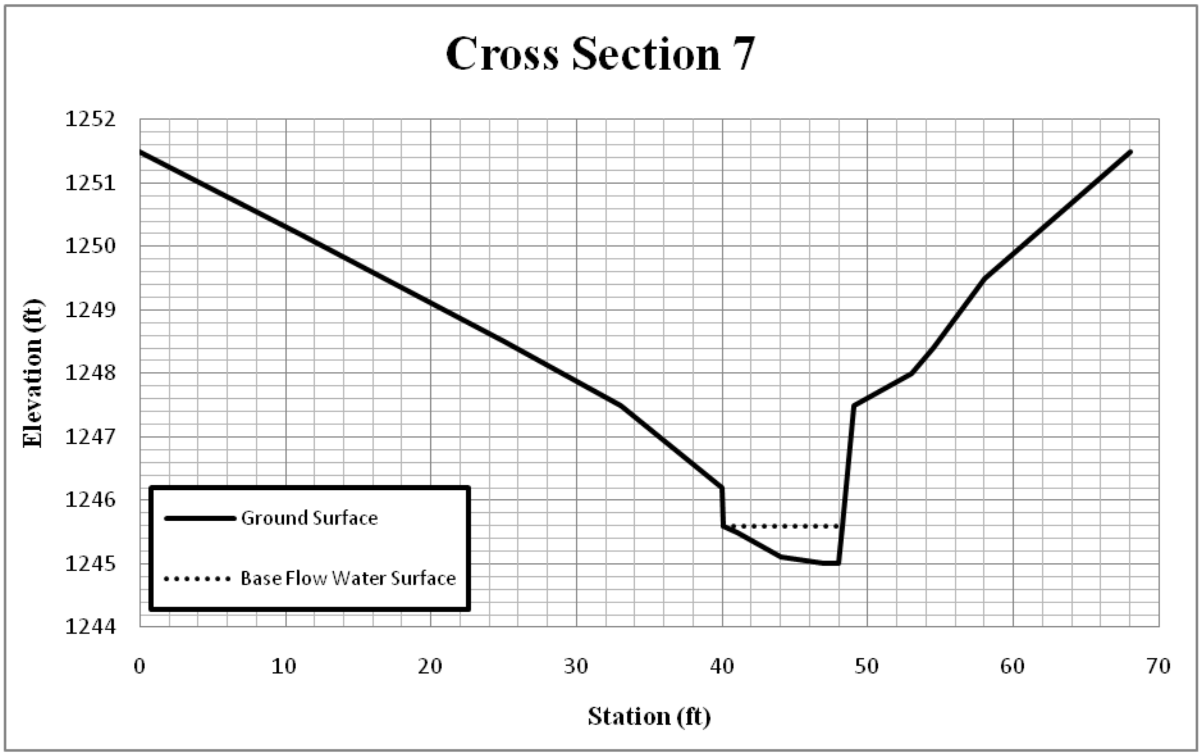

Figure I9. Cross-Section 7

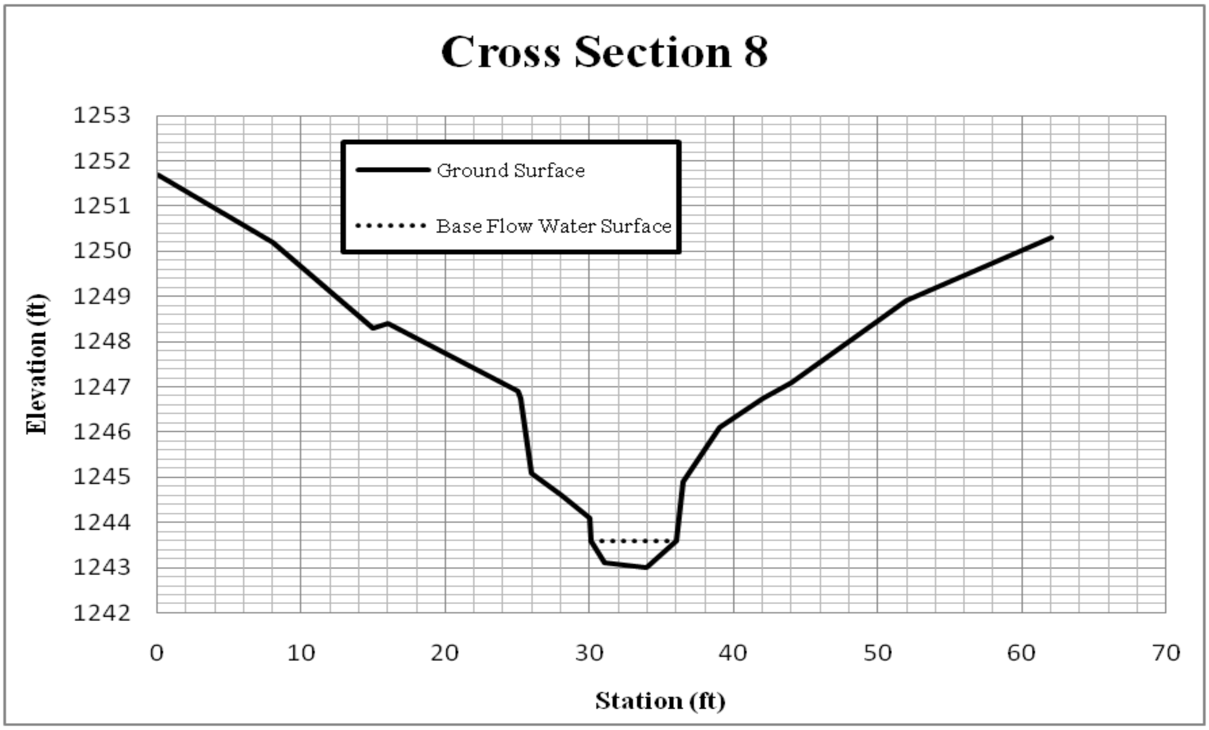

Figure I10. Cross-Section 8

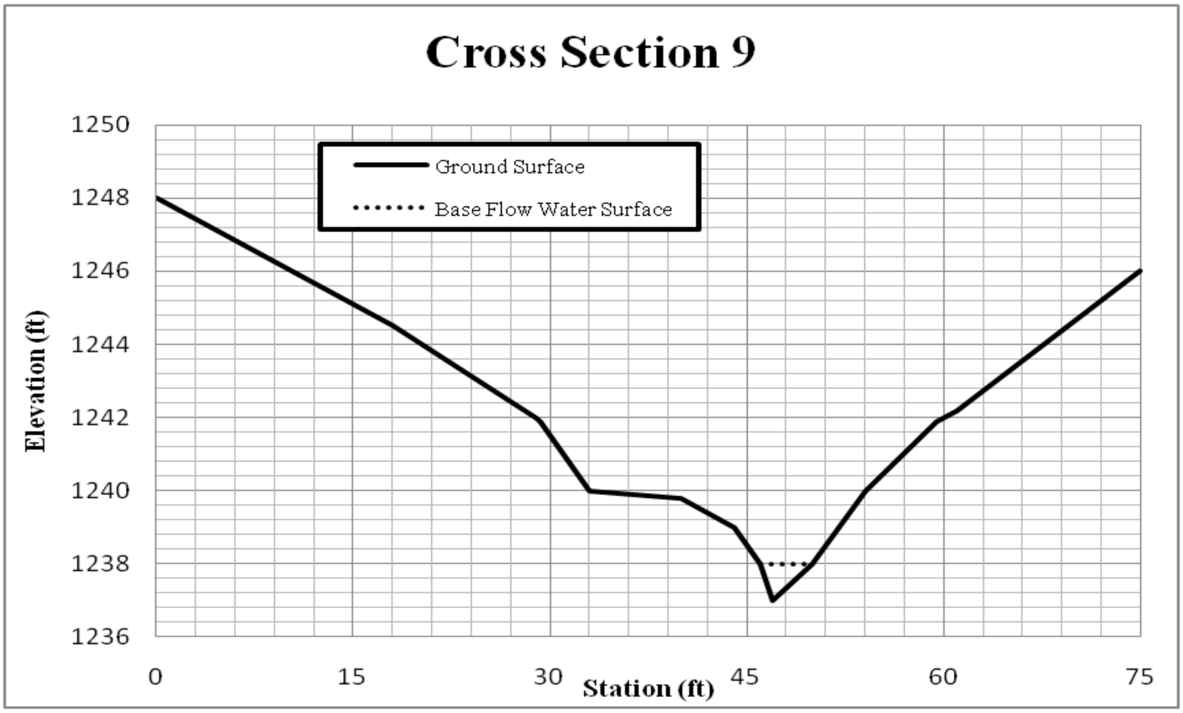

Figure I11. Cross-Section 9

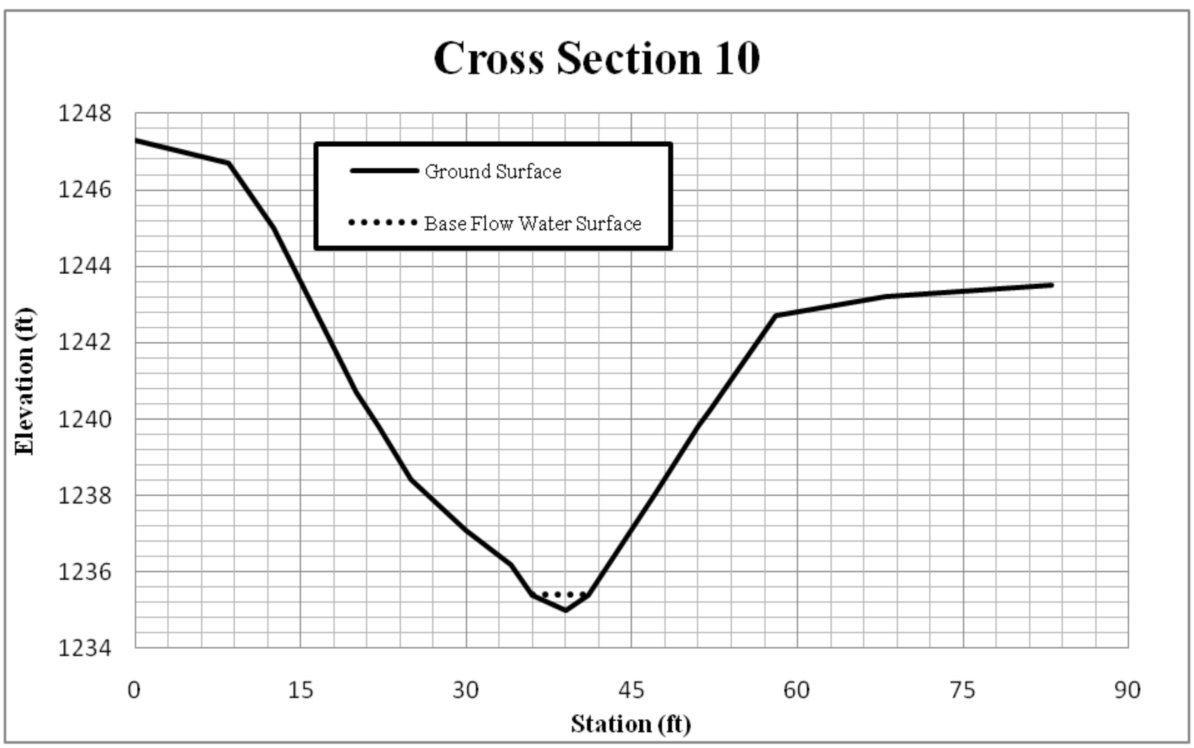

Figure I12. Cross-Section 10

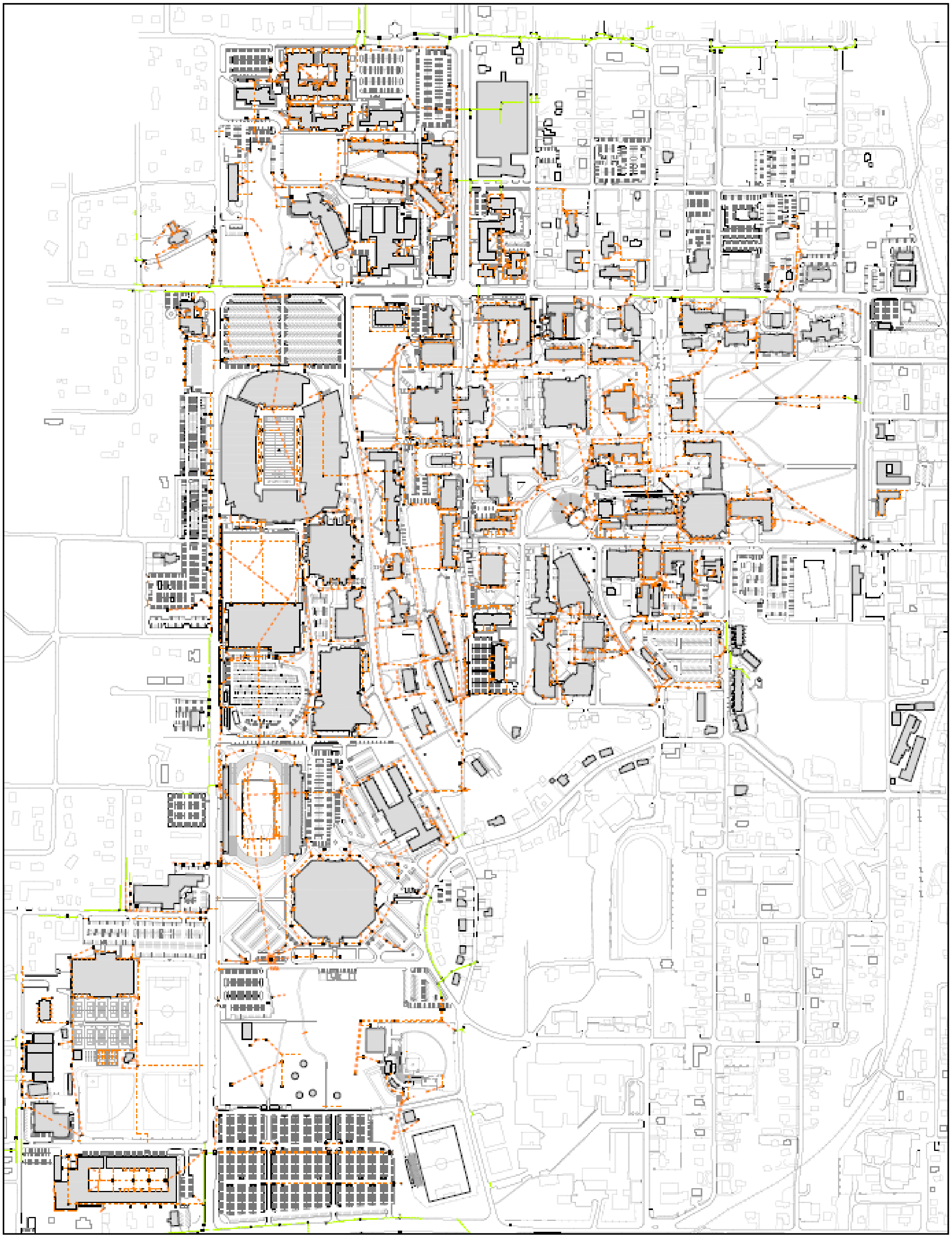

Figure I13. University of Arkansas Underground Drainage Pipes Map

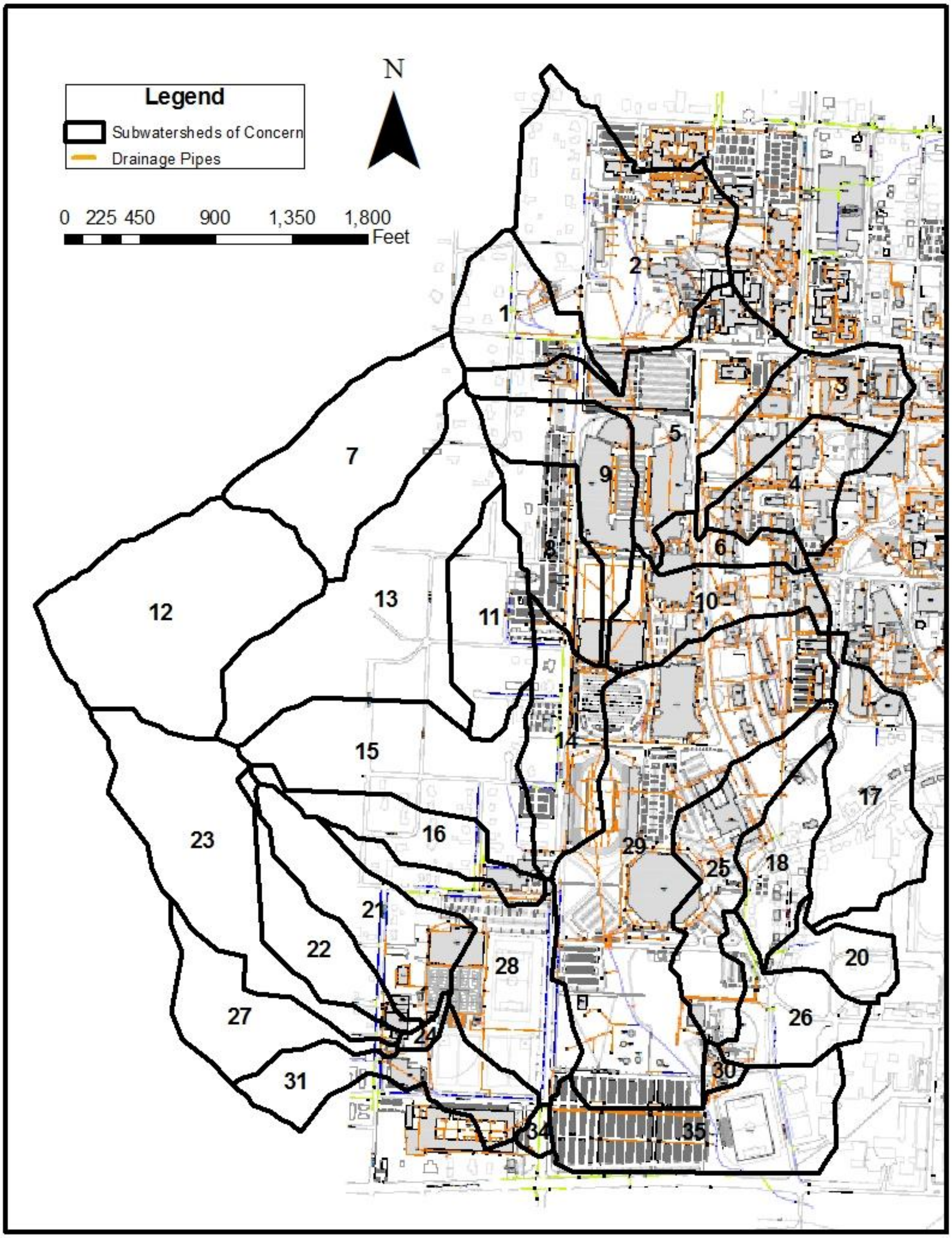

Figure I14. Campus Drainage Pipes Map with Subwatersheds

APPENDIX J

Unit Peak Discharge Values and Calculated Peak Flows for Subwatersheds

for Various Storm Events

Calculated Time of Concentration for Entire Watershed

Calculated Peak Flow for Various Storm Events for Entire Watershed of Concern

Table J1. Unit Peak Discharge and Peak Flow Values for Subwatersheds at Various Storm Events

Watershed	Area (Acres)	Area (mi^2)	CN	Time of Conc. (hr)	2-Year Event				10-Year Event				25-Year Event				50-Year Event				100-Year Event			
					P (in.)	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	10.05	0.016	94	0.29	4.1	3.4	510	27.4	6.2	5.5	510	44.0	7.1	6.4	510	51.1	8.0	7.3	510	58.3	8.9	8.2	510	65.5
2	31.78	0.050	94	0.41	4.1	3.4	448	76.1	6.2	5.5	448	122.2	7.1	6.4	448	142.1	8.0	7.3	448	162.0	8.9	8.2	448	181.9
3	11.91	0.019	98	0.18	4.1	3.9	570	41.0	6.2	6.0	570	63.3	7.1	6.9	570	72.8	8.0	7.8	570	82.3	8.9	8.7	570	91.9
4	10.27	0.016	97	0.10	4.1	3.8	650	39.1	6.2	5.8	650	61.0	7.1	6.7	650	70.3	8.0	7.6	650	79.7	8.9	8.5	650	89.1
5	22.42	0.035	97	0.11	4.1	3.8	650	85.4	6.2	5.8	650	133.0	7.1	6.7	650	153.5	8.0	7.6	650	174.0	8.9	8.5	650	194.4
6	4.50	0.007	99	0.21	4.1	4.0	546	15.3	6.2	6.1	546	23.3	7.1	7.0	546	26.8	8.0	7.9	546	30.2	8.9	8.8	546	33.7
7	20.47	0.032	88	0.80	4.1	2.8	330	29.8	6.2	4.8	330	50.8	7.1	5.7	330	60.0	8.0	6.6	330	69.3	8.9	7.4	330	78.6
8	10.31	0.016	97	0.28	4.1	3.8	519	31.4	6.2	5.8	519	48.8	7.1	6.7	519	56.4	8.0	7.6	519	63.9	8.9	8.5	519	71.4
9	12.49	0.020	98	0.23	4.1	3.9	537	40.5	6.2	6.0	537	62.5	7.1	6.9	537	71.9	8.0	7.8	537	81.3	8.9	8.7	537	90.8
10	11.68	0.018	98	0.06	4.1	3.9	650	45.8	6.2	6.0	650	70.7	7.1	6.9	650	81.4	8.0	7.8	650	92.0	8.9	8.7	650	102.7
11	12.10	0.019	94	0.60	4.1	3.4	380	24.6	6.2	5.5	380	39.5	7.1	6.4	380	45.9	8.0	7.3	380	52.3	8.9	8.2	380	58.8
12	33.02	0.052	85	0.40	4.1	2.5	460	60.5	6.2	4.5	460	106.6	7.1	5.3	460	126.9	8.0	6.2	460	147.5	8.9	7.1	460	168.1
13	32.55	0.051	87	0.72	4.1	2.7	350	48.6	6.2	4.7	350	83.8	7.1	5.6	350	99.3	8.0	6.4	350	114.8	8.9	7.3	350	130.5
14	13.15	0.021	98	0.11	4.1	3.9	650	51.6	6.2	6.0	650	79.7	7.1	6.9	650	91.7	8.0	7.8	650	103.7	8.9	8.7	650	115.7
15	21.83	0.034	89	0.70	4.1	2.9	355	35.3	6.2	4.9	355	59.7	7.1	5.8	355	70.3	8.0	6.7	355	81.0	8.9	7.6	355	91.7
16	9.14	0.014	96	0.88	4.1	3.6	314	16.3	6.2	5.7	314	25.7	7.1	6.6	314	29.7	8.0	7.5	314	33.7	8.9	8.4	314	37.8
17	17.40	0.027	93	0.34	4.1	3.3	487	43.9	6.2	5.4	487	71.2	7.1	6.3	487	83.0	8.0	7.2	487	94.8	8.9	8.1	487	106.7
18	9.06	0.014	95	0.31	4.1	3.5	501	25.0	6.2	5.6	501	39.8	7.1	6.5	501	46.1	8.0	7.4	501	52.5	8.9	8.3	501	58.9
20	5.53	0.009	95	0.24	4.1	3.5	532	16.2	6.2	5.6	532	25.8	7.1	6.5	532	29.9	8.0	7.4	532	34.0	8.9	8.3	532	38.1
21	14.49	0.023	95	0.27	4.1	3.5	519	41.5	6.2	5.6	519	65.9	7.1	6.5	519	76.5	8.0	7.4	519	87.0	8.9	8.3	519	97.5
22	9.23	0.014	87	0.54	4.1	2.7	404	15.9	6.2	4.7	404	27.4	7.1	5.6	404	32.5	8.0	6.4	404	37.6	8.9	7.3	404	42.7
23	23.46	0.037	87	0.98	4.1	2.7	294	29.4	6.2	4.7	294	50.7	7.1	5.6	294	60.1	8.0	6.4	294	69.5	8.9	7.3	294	79.0
24	0.91	0.001	99	0.04	4.1	4.0	650	3.7	6.2	6.1	650	5.6	7.1	7.0	650	6.4	8.0	7.9	650	7.2	8.9	8.8	650	8.1
25	15.22	0.024	97	0.12	4.1	3.8	630	56.2	6.2	5.8	630	87.5	7.1	6.7	630	101.0	8.0	7.6	630	114.4	8.9	8.5	630	127.9
26	9.59	0.015	95	0.10	4.1	3.5	650	34.4	6.2	5.6	650	54.7	7.1	6.5	650	63.4	8.0	7.4	650	72.1	8.9	8.3	650	80.9
27	11.17	0.017	90	0.30	4.1	3.0	505	26.6	6.2	5.0	505	44.4	7.1	5.9	505	52.2	8.0	6.8	505	60.0	8.9	7.7	505	67.8
28	18.87	0.029	97	0.37	4.1	3.8	474	52.4	6.2	5.8	474	81.7	7.1	6.7	474	94.2	8.0	7.6	474	106.8	8.9	8.5	474	119.3
29	53.09	0.083	98	0.31	4.1	3.9	501	160.6	6.2	6.0	501	247.8	7.1	6.9	501	285.1	8.0	7.8	501	322.5	8.9	8.7	501	359.9
30	1.10	0.002	93	0.05	4.1	3.3	650	3.7	6.2	5.4	650	6.0	7.1	6.3	650	7.0	8.0	7.2	650	8.0	8.9	8.1	650	9.0
31	12.96	0.020	96	0.32	4.1	3.6	496	36.5	6.2	5.7	496	57.5	7.1	6.6	496	66.5	8.0	7.5	496	75.5	8.9	8.4	496	84.5
34	0.95	0.001	99	0.03	4.1	4.0	650	3.9	6.2	6.1	650	5.9	7.1	7.0	650	6.8	8.0	7.9	650	7.6	8.9	8.8	650	8.5
35	19.12	0.030	98	0.13	4.1	3.9	620	71.6	6.2	6.0	620	110.4	7.1	6.9	620	127.1	8.0	7.8	620	143.8	8.9	8.7	620	160.4

Table J2. Calculated Time of Concentration for Entire Watershed Based on Longest Flow Path

Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
Sheet	300	Urban: Intensity 1	0.1	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
Shallow Concentrated	680	Unpaved/Paved	0.25	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.26	0.08
Channel: Segment 1	806	Some grass, weeds, little or no brush	0.03	0.019	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	4.79	0.05
Pipe 1	436	Concrete Pipe	0.011	0.009	4.1	3' by 3'	3' by 3'	N/A	N/A	0.9	3.60	0.25	5.10	0.02
Pipe 2	215	Concrete Pipe	0.011	0.009	4.1	3.5	1.75	0.55	1.63	0.97	2.85	0.34	6.25	0.01
Pipe 3	610	Concrete Pipe	0.011	0.009	4.1	4' by 4'	4' by 4'	N/A	N/A	1.6	4.8	0.33	6.18	0.03
Pipe 4	730	Concrete Pipe	0.011	0.009	4.1	7' by 5'	7' by 5'	N/A	N/A	3.5	6.4	0.55	8.59	0.02
Pipe 5	720	Concrete Pipe	0.011	0.009	4.1	7' by 6'	7' by 6'	N/A	N/A	4.2	7.4	0.57	8.81	0.02
Pipe 6	555	Concrete Pipe	0.011	0.009	4.1	5' by 8'	5' by 8'	N/A	N/A	4.0	9.0	0.44	7.48	0.02
Pipe 7	375	Concrete Pipe	0.011	0.009	4.1	5' by 15'	5' by 15'	N/A	N/A	7.5	16.0	0.47	7.75	0.01
Pipe 8	80	Concrete Pipe	0.011	0.009	4.1	3- 4' by 10'	3- 4' by 10'	N/A	N/A	12.0	10.8	1.11	13.79	0.002
Channel: Segment 2	1120	Some grass, weeds, little or no brush	0.03	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.79	0.17
Channel: Segment 3	590	Some grass, weeds, some brush	0.04	0.005	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	1.31	0.12
TOTAL LENGTH	7217												TOTAL T_c	0.85

Table J3. Calculated Peak Flows for Entire Watershed of Concern

Length (ft)	7282				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	94				
S (in.)	0.69				
Time of	0.85				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	3	5.4	6.3	7.2	8.1
q_{um} (csm/in)	320	320	320	320	320
q_p (cfs)	765	1233	1435	1638	1840

APPENDIX K

Mean Annual Precipitation Map of the U.S.

NSS Program Flood Frequency Analysis Values for Peak Flow at Various Storm Events

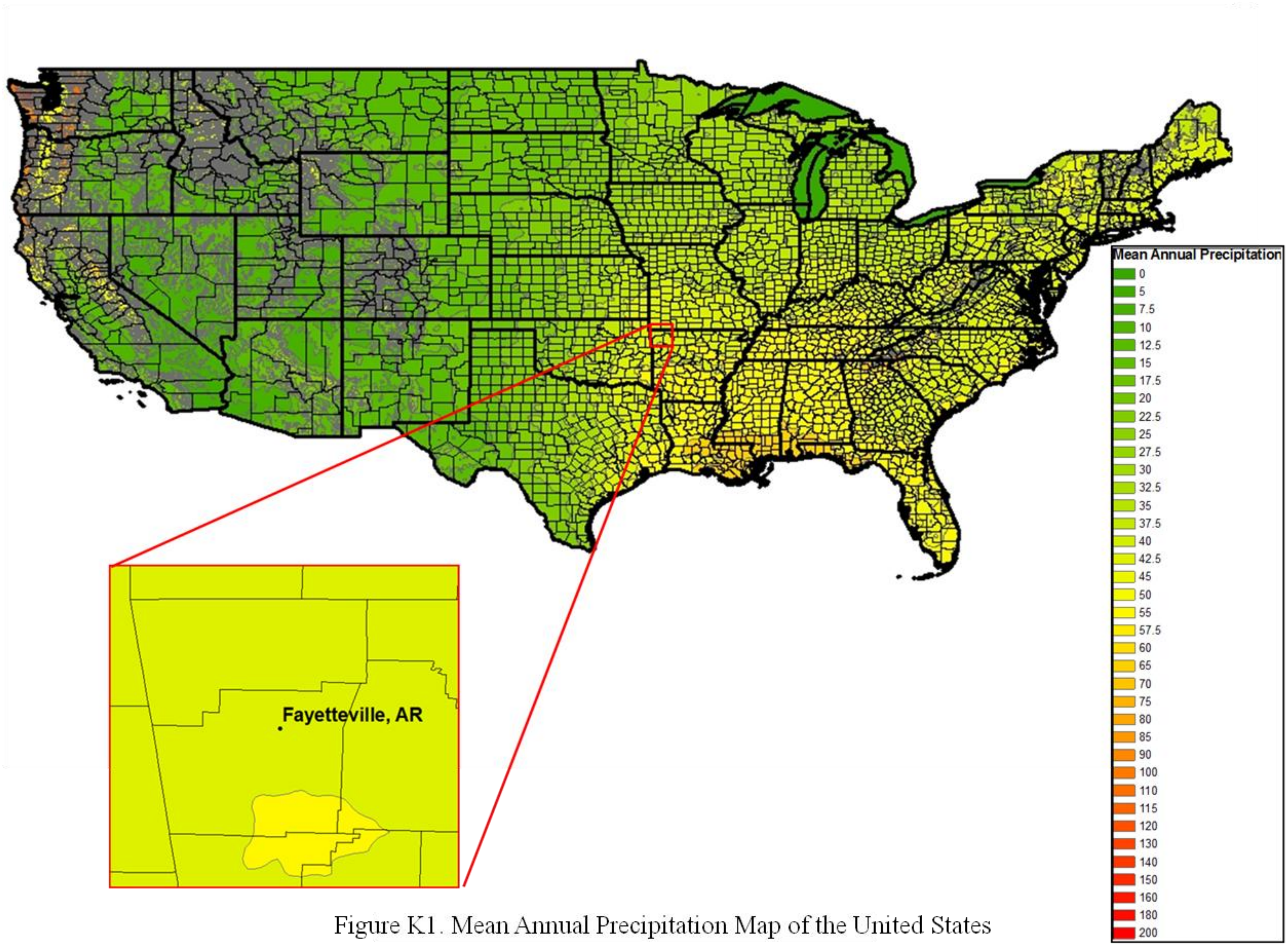

Figure K1. Mean Annual Precipitation Map of the United States

Table K1. NSS Program Peak Flow Calculations

Watershed	Area (mi^2)	Slope (ft/ft)	Slope (ft/mi)	Mean Elevation (ft)	Mean Annual Precip. (in)	Peak Flow (cfs)				
						2-Year	10-Year	25-Year	50-Year	100-Year
1	0.016	0.030	160	434	42.5	15.1	33.6	52.3	94.8	118.1
2	0.050	0.014	73	434	42.5	26.6	56.7	86.1	153.1	189.2
3	0.019	0.017	91	432	42.5	13.5	29.2	44.7	79.4	98.4
4	0.016	0.015	80	427	42.5	11.4	24.3	37.1	65.6	81.2
5	0.035	0.018	96	422	42.5	22.3	48.4	74.2	133.3	165.3
6	0.007	0.035	187	423	42.5	8.4	19.1	29.8	54.1	67.6
7	0.032	0.027	144	427	42.5	24.8	55.1	85.5	155.8	194.0
8	0.016	0.025	134	419	42.5	13.9	30.8	47.7	86.3	107.4
9	0.020	0.033	174	420	42.5	18.1	40.7	63.5	116.2	145.0
10	0.018	0.009	46	419	42.5	9.8	20.4	30.6	53.1	65.3
11	0.019	0.026	139	415	42.5	15.9	35.3	54.9	99.5	124.0
12	0.052	0.021	112	431	42.5	32.7	71.4	110.0	199.1	247.2
13	0.051	0.022	119	420	42.5	32.5	71.5	110.4	200.7	249.5
14	0.021	0.003	17	387	42.5	6.6	13.1	19.2	32.2	39.3
15	0.034	0.024	129	418	42.5	24.6	54.4	84.2	153.1	190.6
16	0.014	0.026	139	418	42.5	12.9	28.5	44.3	80.1	99.8
17	0.027	0.029	154	416	42.5	22.1	49.3	76.8	140.4	175.1
18	0.014	0.030	158	410	42.5	13.3	29.8	46.5	84.6	105.5
20	0.009	0.031	162	397	42.5	8.9	20.1	31.4	57.0	71.2
21	0.023	0.034	179	417	42.5	20.4	46.1	72.1	132.4	165.3
22	0.014	0.026	135	418	42.5	12.8	28.4	44.0	79.5	99.0
23	0.037	0.019	98	420	42.5	23.2	50.5	77.6	139.5	173.1
24	0.001	0.004	20	387	42.5	0.9	1.8	2.6	4.3	5.3
25	0.024	0.023	121	410	42.5	17.8	39.3	60.8	110.0	136.9
26	0.015	0.024	126	396	42.5	12.3	27.3	42.3	76.6	95.4
27	0.017	0.020	106	404	42.5	13.0	28.6	44.1	79.3	98.5
28	0.029	0.029	151	403	42.5	22.8	51.0	79.4	145.6	181.7
29	0.083	0.006	30	412	42.5	26.2	53.2	78.9	136.7	167.7
30	0.002	0.004	22	384	42.5	1.1	2.1	3.2	5.2	6.4
31	0.020	0.011	60	393	42.5	11.3	24.1	36.6	64.6	80.0
34	0.001	0.004	19	385	42.5	0.9	1.8	2.6	4.3	5.3
35	0.030	0.004	19	391	42.5	9.5	18.8	27.5	46.6	57.1

APPENDIX L

HEC-SSP Bulletin 17B Plot

HEC-SSP Tabular Results

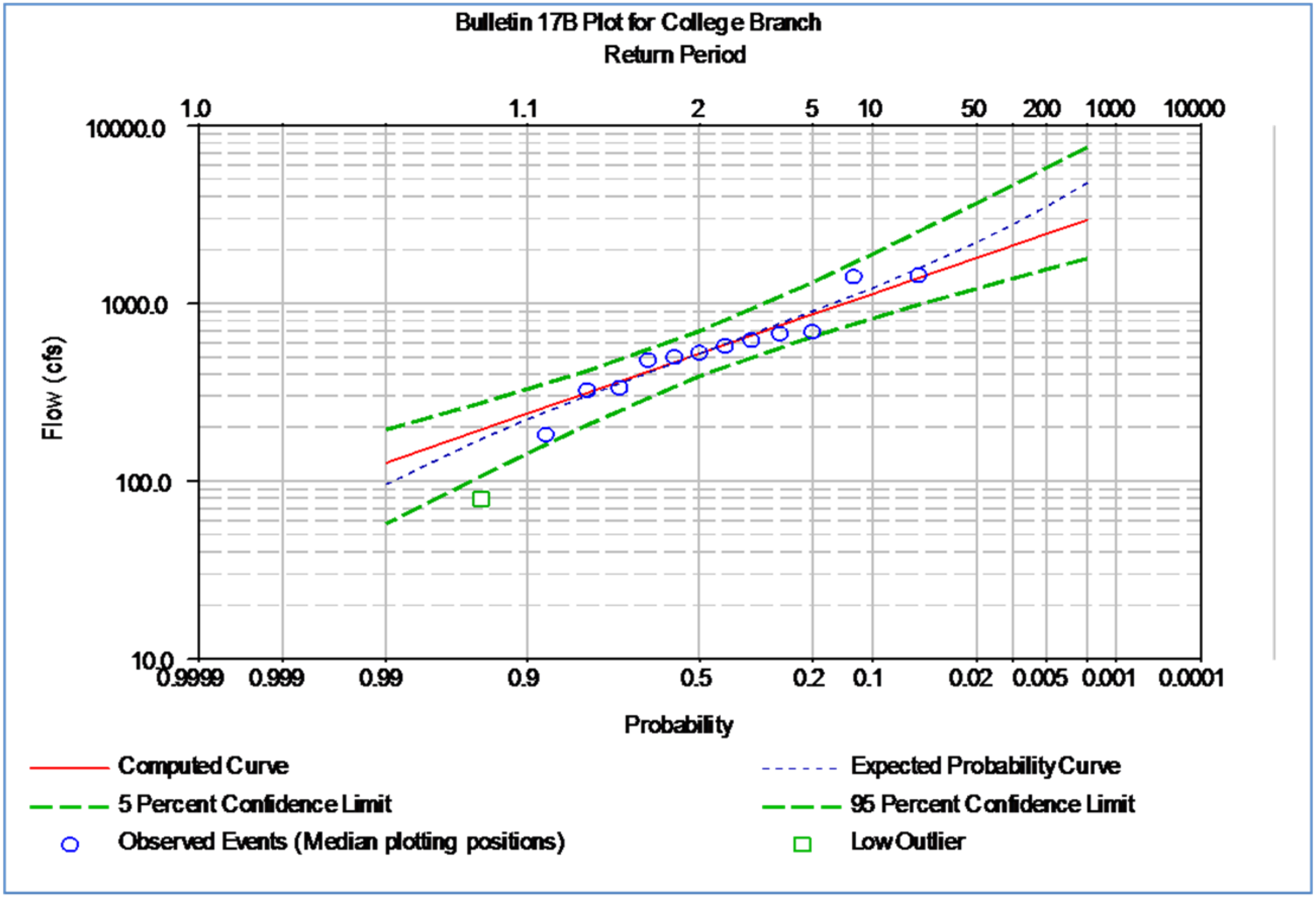

Figure L1. Bulletin 17B Plot for College Branch

Table L1. Tabular Results from Bulletin 17B Analysis by HEC-SSP

Storm Event (Year)	Percent Chance Exceedance	Computed Curve Flow in cfs	Expected Prob. Flow in cfs	Confidence Limits Flow in cfs	
				0.05	0.95
500	0.2	2946.5	4767.1	7536	1790
200	0.5	2458.6	3508	5776.1	1552.9
100	1	2117.1	2782	4641.6	1379.4
50	2	1797.6	2199	3659.4	1210
20	5	1406	1590.1	2570.4	990
10	10	1129.8	1218.7	1887.9	823.4
5	20	866.6	900.6	1313.6	650.8
2	50	521	521	698.7	388.6
1.25	80	312.6	300.7	416.3	206.3
1.11	90	239.2	221.5	328.3	143.1
1.05	95	191.7	169.2	272.4	104.7
1.01	99	126.4	95.6	194.5	57.4

APPENDIX M

HEC-HMS Input Parameters and Calculated Lag Time

Mean Monthly Discharge for USGS Gage Station

HEC-HMS Output Data for Each Storm Event

Table M1. HEC-HMS Input Parameters and Calculated Lag Time								
Watershed	Area (mi^2)	Slope (%)	Length of Flow (ft)	CN	Initial Abstraction (in)	S (in)	Lag time (hours)	Lag time (min)
1	0.016	3.0	1125	94	0.13	0.6	0.12	7.1
2	0.050	1.4	1921	94	0.13	0.6	0.27	16.1
3	0.019	1.7	1800	98	0.04	0.2	0.18	11.0
4	0.016	1.5	920	97	0.06	0.3	0.12	7.3
5	0.035	1.8	1100	97	0.06	0.3	0.13	7.7
6	0.007	3.5	860	99	0.02	0.1	0.07	4.0
7	0.032	2.7	1470	88	0.27	1.4	0.20	12.0
8	0.016	2.5	1250	97	0.06	0.3	0.12	7.2
9	0.020	3.3	1060	98	0.04	0.2	0.09	5.2
10	0.018	0.9	805	98	0.04	0.2	0.14	8.1
11	0.019	2.6	1520	94	0.13	0.6	0.16	9.7
12	0.052	2.1	1650	85	0.35	1.8	0.28	16.6
13	0.051	2.2	2225	87	0.30	1.5	0.32	19.0
14	0.021	0.3	940	98	0.04	0.2	0.25	15.2
15	0.034	2.4	2245	89	0.25	1.2	0.28	17.0
16	0.014	2.6	2200	96	0.08	0.4	0.20	11.7
17	0.027	2.9	1680	93	0.15	0.8	0.17	10.4
18	0.014	3.0	1435	95	0.11	0.5	0.14	8.2
20	0.009	3.1	620	95	0.11	0.5	0.07	4.2
21	0.023	3.4	1510	95	0.11	0.5	0.13	8.0
22	0.014	2.6	1800	87	0.30	1.5	0.25	15.0
23	0.037	1.9	2780	87	0.30	1.5	0.42	25.0
24	0.001	0.4	130	99	0.02	0.1	0.04	2.7
25	0.024	2.3	1400	97	0.06	0.3	0.14	8.3
26	0.015	2.4	840	95	0.11	0.5	0.10	6.0
27	0.017	2.0	1700	90	0.22	1.1	0.24	14.5
28	0.029	2.9	2450	97	0.06	0.3	0.19	11.6
29	0.083	0.6	4025	98	0.04	0.2	0.61	36.6
30	0.002	0.4	240	93	0.15	0.8	0.10	5.8
31	0.020	1.1	1850	96	0.08	0.4	0.26	15.5
34	0.001	0.4	276	99	0.02	0.1	0.08	5.0
35	0.030	0.4	1510	98	0.04	0.2	0.35	20.9

Table M2. Mean Monthly Discharge for USGS Gage Station 07048480

(http://waterdata.usgs.gov/nwis/nwisman/?site_no=07048480&agency_cd=USGS)

YEAR	Monthly mean in cfs (Calculation Period: 1996-10-01 -> 2010-09-30)											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1996										1.53	5.9	1.33
1997	0.183	3.24	1.53	0.995	0.895	1.95	0.751	1.37	1.08	1.69	0.645	1.08
1998	4.84	1.49	3.99	0.791	1.06	0.857	0.695	0.281	0.786	1.86	1.8	1.01
1999	1.58	1.66	2.98	2.24	3.38	3.17	0.504	0.642	0.713	0.508	0.377	1.66
2000	1.29	1.25	0.98	0.503	1.77	6.52	1.15	0.377	1.44	1.17	2.49	1.14
2001	1.46	3.88	1.06	1.12	2.68	1.45	1.07	0.971	2.36	1.78	1.29	3.78
2002	1.89	1.04	2.87	4.16	2.83	1.13	0.453	2.52	0.206	0.465	0.593	1.74
2003	0.69	1.32	0.983	0.739	2.45	1.55	0.787	0.694	0.851	2.32	2.4	1.96
2004	1	0.472	0.858	4.19	1.07	1.5	1.83	0.986	0.254	3.1	2.09	1.36
2005	1.58	0.177	0.5	0.761	0.394	0.566	0.245	0.216	0.448	0.281	0.034	0.22
2006	0.372	0.251	2.43	2.31	1.73	0.728	0.734	1.22	9.27	0.602	1.24	0.838
2007	1.19	0.487	0.431	0.828	1.81	0.945	0.604	0.743	1.03	0.603	0.448	1.91
2008	0.321	0.623	2.83	2.57	1.06	0.921	0.718	0.763	1.25	0.242	0.069	0.867
2009	1.29	1.12	1.56	0.965	2.42	0.483	1.11	1.92	2.16	5.28	0.449	0.467
2010	1.09	1.17	1.58	1.21	4.04	0.67	5.25	0.394	2.35			
Mean of monthly Discharge	1.3	1.3	1.8	1.7	2	1.6	1.1	0.94	1.7	1.5	1.4	1.4

** No Incomplete data have been used for statistical calculation

Table M3. HEC-HMS Run Results for 2-Year Storm Event				
Hydrologic Element	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.016	17.3	01Mar2010, 12:30	6.5
2	0.05	49.8	01Mar2010, 12:30	12.7
3	0.019	21.2	01Mar2010, 12:30	7.5
4	0.016	18	01Mar2010, 12:30	6.8
5	0.035	37.2	01Mar2010, 12:30	10.6
6	0.007	9	01Mar2010, 12:30	5.1
7	0.032	29	01Mar2010, 12:30	8.4
8	0.016	18	01Mar2010, 12:30	6.8
9	0.02	22.2	01Mar2010, 12:30	7.8
10	0.018	20.2	01Mar2010, 12:30	7.3
11	0.019	20.2	01Mar2010, 12:30	7.1
12	0.052	41.7	01Mar2010, 12:30	10.7
13	0.051	42.1	01Mar2010, 12:30	11
14	0.021	23.2	01Mar2010, 12:30	8
15	0.034	30.8	01Mar2010, 12:30	8.9
16	0.014	15.8	01Mar2010, 12:30	6.4
17	0.027	27.5	01Mar2010, 12:30	8.4
18	0.014	15.6	01Mar2010, 12:30	6.3
20	0.009	10.7	01Mar2010, 12:30	5.3
21	0.023	24.4	01Mar2010, 12:30	8
22	0.014	13.4	01Mar2010, 12:30	5.7
23	0.037	28.8	01Mar2010, 12:30	9
24	0.001	2.8	01Mar2010, 12:30	3.8
25	0.024	26.1	01Mar2010, 12:30	8.4
26	0.015	16.6	01Mar2010, 12:30	6.5
27	0.017	17	01Mar2010, 12:30	6.4
28	0.029	31.1	01Mar2010, 12:30	9.4
29	0.083	67.9	01Mar2010, 12:30	20.7
30	0.002	3.7	01Mar2010, 12:30	4
31	0.02	21.7	01Mar2010, 12:30	7.5
34	0.001	2.8	01Mar2010, 12:30	3.8
35	0.03	31	01Mar2010, 12:30	9.8
Maple Street	0.101	104.3	01Mar2010, 12:30	29.9
J10	0.161	172.6	01Mar2010, 12:30	56.8
Leroy Pond	0.489	467.6	01Mar2010, 12:30	146.2
Hwy62	0.766	756.5	01Mar2010, 12:30	254.8

Table M4. HEC-HMS Run Results for 10-Year Storm Event				
Hydrologic Element	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.016	26	01Mar2010, 12:30	8.3
2	0.05	76.6	01Mar2010, 12:30	18.3
3	0.019	31.2	01Mar2010, 12:30	9.7
4	0.016	26.5	01Mar2010, 12:30	8.6
5	0.035	55.8	01Mar2010, 12:30	14.5
6	0.007	12.7	01Mar2010, 12:30	5.9
7	0.032	46.7	01Mar2010, 12:30	11.9
8	0.016	26.5	01Mar2010, 12:30	8.6
9	0.02	32.8	01Mar2010, 12:30	10
10	0.018	29.7	01Mar2010, 12:30	9.4
11	0.019	30.5	01Mar2010, 12:30	9.2
12	0.052	70.1	01Mar2010, 12:30	16.1
13	0.051	69.5	01Mar2010, 12:30	16.4
14	0.021	34.3	01Mar2010, 12:30	10.3
15	0.034	49.3	01Mar2010, 12:30	12.6
16	0.014	23.3	01Mar2010, 12:30	7.9
17	0.027	42.2	01Mar2010, 12:30	11.4
18	0.014	23.1	01Mar2010, 12:30	7.8
20	0.009	15.5	01Mar2010, 12:30	6.3
21	0.023	36.8	01Mar2010, 12:30	10.5
22	0.014	21.1	01Mar2010, 12:30	7.1
23	0.037	47.7	01Mar2010, 12:30	12.9
24	0.001	3.4	01Mar2010, 12:30	4
25	0.024	38.8	01Mar2010, 12:30	11.1
26	0.015	24.6	01Mar2010, 12:30	8.1
27	0.017	26.3	01Mar2010, 12:30	8.2
28	0.029	46.5	01Mar2010, 12:30	12.7
29	0.083	102.5	01Mar2010, 12:30	29.9
30	0.002	4.8	01Mar2010, 12:30	4.2
31	0.02	32.3	01Mar2010, 12:30	9.7
34	0.001	3.4	01Mar2010, 12:30	4
35	0.03	46.2	01Mar2010, 12:30	13.2
Maple Street	0.101	158.3	01Mar2010, 12:30	41.1
J10	0.161	258.4	01Mar2010, 12:30	74.7
Leroy Pond	0.489	720.6	01Mar2010, 12:30	199.6
Hwy62	0.766	1156.5	01Mar2010, 12:30	338.7

Table M5. HEC-HMS Run Results for 25-Year Storm Event				
Hydrologic Element	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.016	29.6	01Mar2010, 12:30	9.1
2	0.05	88	01Mar2010, 12:30	20.6
3	0.019	35.5	01Mar2010, 12:30	10.6
4	0.016	30.1	01Mar2010, 12:30	9.4
5	0.035	63.7	01Mar2010, 12:30	16.2
6	0.007	14.3	01Mar2010, 12:30	6.2
7	0.032	54.2	01Mar2010, 12:30	13.3
8	0.016	30.1	01Mar2010, 12:30	9.4
9	0.02	37.3	01Mar2010, 12:30	10.9
10	0.018	33.8	01Mar2010, 12:30	10.2
11	0.019	34.9	01Mar2010, 12:30	10.1
12	0.052	82.3	01Mar2010, 12:30	18.5
13	0.051	81.2	01Mar2010, 12:30	18.8
14	0.021	39	01Mar2010, 12:30	11.3
15	0.034	57.2	01Mar2010, 12:30	14.1
16	0.014	26.5	01Mar2010, 12:30	8.6
17	0.027	48.4	01Mar2010, 12:30	12.7
18	0.014	26.3	01Mar2010, 12:30	8.5
20	0.009	17.6	01Mar2010, 12:30	6.8
21	0.023	42.1	01Mar2010, 12:30	11.6
22	0.014	24.4	01Mar2010, 12:30	7.8
23	0.037	55.7	01Mar2010, 12:30	14.6
24	0.001	3.6	01Mar2010, 12:30	4
25	0.024	44.3	01Mar2010, 12:30	12.3
26	0.015	28.1	01Mar2010, 12:30	8.8
27	0.017	30.3	01Mar2010, 12:30	9
28	0.029	53.1	01Mar2010, 12:30	14.1
29	0.083	117.2	01Mar2010, 12:30	33.9
30	0.002	5.3	01Mar2010, 12:30	4.3
31	0.02	36.9	01Mar2010, 12:30	10.7
34	0.001	3.6	01Mar2010, 12:30	4
35	0.03	52.7	01Mar2010, 12:30	14.6
Maple Street	0.101	181.4	01Mar2010, 12:30	45.9
J10	0.161	295.1	01Mar2010, 12:30	82.4
Leroy Pond	0.489	828.6	01Mar2010, 12:30	222.7
Hwy62	0.766	1327.3	01Mar2010, 12:30	374.9

Table M6. HEC-HMS Run Results for 50-Year Storm Event				
Hydrologic Element	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.016	33.3	01Mar2010, 12:30	9.8
2	0.05	99.4	01Mar2010, 12:30	23
3	0.019	39.8	01Mar2010, 12:30	11.5
4	0.016	33.7	01Mar2010, 12:30	10.2
5	0.035	71.7	01Mar2010, 12:30	17.9
6	0.007	15.8	01Mar2010, 12:30	6.6
7	0.032	61.7	01Mar2010, 12:30	14.8
8	0.016	33.7	01Mar2010, 12:30	10.2
9	0.02	41.8	01Mar2010, 12:30	11.9
10	0.018	37.8	01Mar2010, 12:30	11.1
11	0.019	39.2	01Mar2010, 12:30	11
12	0.052	94.5	01Mar2010, 12:30	20.9
13	0.051	92.9	01Mar2010, 12:30	21.1
14	0.021	43.8	01Mar2010, 12:30	12.3
15	0.034	65.1	01Mar2010, 12:30	15.7
16	0.014	29.6	01Mar2010, 12:30	9.2
17	0.027	54.6	01Mar2010, 12:30	13.9
18	0.014	29.5	01Mar2010, 12:30	9.2
20	0.009	19.6	01Mar2010, 12:30	7.2
21	0.023	47.3	01Mar2010, 12:30	12.7
22	0.014	27.7	01Mar2010, 12:30	8.4
23	0.037	63.7	01Mar2010, 12:30	16.3
24	0.001	3.8	01Mar2010, 12:30	4.1
25	0.024	49.7	01Mar2010, 12:30	13.4
26	0.015	31.5	01Mar2010, 12:30	9.5
27	0.017	34.3	01Mar2010, 12:30	9.8
28	0.029	59.7	01Mar2010, 12:30	15.4
29	0.083	132	01Mar2010, 12:30	37.9
30	0.002	5.7	01Mar2010, 12:30	4.4
31	0.02	41.4	01Mar2010, 12:30	11.7
34	0.001	3.8	01Mar2010, 12:30	4.1
35	0.03	59.1	01Mar2010, 12:30	16
Maple Street	0.101	204.4	01Mar2010, 12:30	50.8
J10	0.161	331.6	01Mar2010, 12:30	90
Leroy Pond	0.489	936.3	01Mar2010, 12:30	245.9
Hwy62	0.766	1497.6	01Mar2010, 12:30	411.2

Table M7. HEC-HMS Run Results for 100-Year Storm Event				
Hydrologic Element	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Volume (ac-ft)
1	0.016	37	01Mar2010, 12:30	10.6
2	0.05	110.7	01Mar2010, 12:30	25.4
3	0.019	44.1	01Mar2010, 12:30	12.4
4	0.016	37.4	01Mar2010, 12:30	10.9
5	0.035	79.6	01Mar2010, 12:30	19.6
6	0.007	17.4	01Mar2010, 12:30	6.9
7	0.032	69.2	01Mar2010, 12:30	16.3
8	0.016	37.4	01Mar2010, 12:30	10.9
9	0.02	46.4	01Mar2010, 12:30	12.9
10	0.018	41.9	01Mar2010, 12:30	11.9
11	0.019	43.6	01Mar2010, 12:30	11.9
12	0.052	106.6	01Mar2010, 12:30	23.3
13	0.051	104.5	01Mar2010, 12:30	23.5
14	0.021	48.5	01Mar2010, 12:30	13.3
15	0.034	72.9	01Mar2010, 12:30	17.3
16	0.014	32.8	01Mar2010, 12:30	9.9
17	0.027	60.8	01Mar2010, 12:30	15.2
18	0.014	32.7	01Mar2010, 12:30	9.8
20	0.009	21.7	01Mar2010, 12:30	7.6
21	0.023	52.6	01Mar2010, 12:30	13.8
22	0.014	31	01Mar2010, 12:30	9.1
23	0.037	71.8	01Mar2010, 12:30	18.1
24	0.001	4	01Mar2010, 12:30	4.1
25	0.024	55.2	01Mar2010, 12:30	14.6
26	0.015	34.9	01Mar2010, 12:30	10.3
27	0.017	38.2	01Mar2010, 12:30	10.6
28	0.029	66.3	01Mar2010, 12:30	16.8
29	0.083	146.7	01Mar2010, 12:30	41.8
30	0.002	6.2	01Mar2010, 12:30	4.5
31	0.02	46	01Mar2010, 12:30	12.6
34	0.001	4	01Mar2010, 12:30	4.1
35	0.03	65.6	01Mar2010, 12:30	17.5
Maple Street	0.101	227.3	01Mar2010, 12:30	55.6
J10	0.161	368.1	01Mar2010, 12:30	97.7
Leroy Pond	0.489	1043.8	01Mar2010, 12:30	269.1
Hwy62	0.766	1667.6	01Mar2010, 12:30	447.6

APPENDIX N

Tabular Comparison of Runoff Analysis Results

Percentages of Watershed Flow for Subwatersheds for Storm Events

Table N1. Comparison of Runoff Analysis Methods for Subwatersheds of College Branch Watershed

Watershed	2-Year Peak Flow (cfs)			10-Year Peak Flow (cfs)			25-Year Peak Flow (cfs)			50-Year Peak Flow (cfs)			100-Year Peak Flow (cfs)		
	NRCS Method	HEC-HMS	NSS	NRCS Method	HEC-HMS	NSS	NRCS Method	HEC-HMS	NSS	NRCS Method	HEC-HMS	NSS	NRCS Method	HEC-HMS	NSS
1	27.4	17.3	15.1	44.0	26	33.6	51.1	29.6	52.3	58.3	33.3	94.8	65.5	37	118.1
2	76.1	49.8	26.6	122.2	76.6	56.7	142.1	88	86.1	162.0	99.4	153.1	181.9	110.7	189.2
3	41.0	21.2	13.5	63.3	31.2	29.2	72.8	35.5	44.7	82.3	39.8	79.4	91.9	44.1	98.4
4	39.1	18	11.4	61.0	26.5	24.3	70.3	30.1	37.1	79.7	33.7	65.6	89.1	37.4	81.2
5	85.4	37.2	22.3	133.0	55.8	48.4	153.5	63.7	74.2	174.0	71.7	133.3	194.4	79.6	165.3
6	15.3	9	8.4	23.3	12.7	19.1	26.8	14.3	29.8	30.2	15.8	54.1	33.7	17.4	67.6
7	29.8	29	24.8	50.8	46.7	55.1	60.0	54.2	85.5	69.3	61.7	155.8	78.6	69.2	194.0
8	31.4	18	13.9	48.8	26.5	30.8	56.4	30.1	47.7	63.9	33.7	86.3	71.4	37.4	107.4
9	40.5	22.2	18.1	62.5	32.8	40.7	71.9	37.3	63.5	81.3	41.8	116.2	90.8	46.4	145.0
10	45.8	20.2	9.8	70.7	29.7	20.4	81.4	33.8	30.6	92.0	37.8	53.1	102.7	41.9	65.3
11	24.6	20.2	15.9	39.5	30.5	35.3	45.9	34.9	54.9	52.3	39.2	99.5	58.8	43.6	124.0
12	60.5	41.7	32.7	106.6	70.1	71.4	126.9	82.3	110.0	147.5	94.5	199.1	168.1	106.6	247.2
13	48.6	42.1	32.5	83.8	69.5	71.5	99.3	81.2	110.4	114.8	92.9	200.7	130.5	104.5	249.5
14	51.6	23.2	6.6	79.7	34.3	13.1	91.7	39	19.2	103.7	43.8	32.2	115.7	48.5	39.3
15	35.3	30.8	24.6	59.7	49.3	54.4	70.3	57.2	84.2	81.0	65.1	153.1	91.7	72.9	190.6
16	16.3	15.8	12.9	25.7	23.3	28.5	29.7	26.5	44.3	33.7	29.6	80.1	37.8	32.8	99.8
17	43.9	27.5	22.1	71.2	42.2	49.3	83.0	48.4	76.8	94.8	54.6	140.4	106.7	60.8	175.1
18	25.0	15.6	13.3	39.8	23.1	29.8	46.1	26.3	46.5	52.5	29.5	84.6	58.9	32.7	105.5
20	16.2	10.7	8.9	25.8	15.5	20.1	29.9	17.6	31.4	34.0	19.6	57.0	38.1	21.7	71.2
21	41.5	24.4	20.4	65.9	36.8	46.1	76.5	42.1	72.1	87.0	47.3	132.4	97.5	52.6	165.3
22	15.9	13.4	12.8	27.4	21.1	28.4	32.5	24.4	44.0	37.6	27.7	79.5	42.7	31	99.0
23	29.4	28.8	23.2	50.7	47.7	50.5	60.1	55.7	77.6	69.5	63.7	139.5	79.0	71.8	173.1
24	3.7	2.8	0.9	5.6	3.4	1.8	6.4	3.6	2.6	7.2	3.8	4.3	8.1	4	5.3
25	56.2	26.1	17.8	87.5	38.8	39.3	101.0	44.3	60.8	114.4	49.7	110.0	127.9	55.2	136.9
26	34.4	16.6	12.3	54.7	24.6	27.3	63.4	28.1	42.3	72.1	31.5	76.6	80.9	34.9	95.4
27	26.6	17	13.0	44.4	26.3	28.6	52.2	30.3	44.1	60.0	34.3	79.3	67.8	38.2	98.5
28	52.4	31.1	22.8	81.7	46.5	51.0	94.2	53.1	79.4	106.8	59.7	145.6	119.3	66.3	181.7
29	160.6	67.9	26.2	247.8	102.5	53.2	285.1	117.2	78.9	322.5	132	136.7	359.9	146.7	167.7
30	3.7	3.7	1.1	6.0	4.8	2.1	7.0	5.3	3.2	8.0	5.7	5.2	9.0	6.2	6.4
31	36.5	21.7	11.3	57.5	32.3	24.1	66.5	36.9	36.6	75.5	41.4	64.6	84.5	46	80.0
34	3.9	2.8	0.9	5.9	3.4	1.8	6.8	3.6	2.6	7.6	3.8	4.3	8.5	4	5.3
35	71.6	31	9.5	110.4	46.2	18.8	127.1	52.7	27.5	143.8	59.1	46.6	160.4	65.6	57.1

Table N2. Percentages of Watershed Flow Rate for Subwatersheds for Storm Events					
Watershed	2-Year Percentages	10-Year Percentages	25-Year Percentages	50-Year Percentages	100-Year Percentages
1	3.6%	3.6%	3.6%	3.6%	3.6%
2	10.0%	9.9%	9.9%	9.9%	9.9%
3	5.4%	5.1%	5.1%	5.0%	5.0%
4	5.1%	4.9%	4.9%	4.9%	4.8%
5	11.2%	10.8%	10.7%	10.6%	10.6%
6	2.0%	1.9%	1.9%	1.8%	1.8%
7	3.9%	4.1%	4.2%	4.2%	4.3%
8	4.1%	4.0%	3.9%	3.9%	3.9%
9	5.3%	5.1%	5.0%	5.0%	4.9%
10	6.0%	5.7%	5.7%	5.6%	5.6%
11	3.2%	3.2%	3.2%	3.2%	3.2%
12	7.9%	8.6%	8.8%	9.0%	9.1%
13	6.3%	6.8%	6.9%	7.0%	7.1%
14	6.7%	6.5%	6.4%	6.3%	6.3%
15	4.6%	4.8%	4.9%	4.9%	5.0%
16	2.1%	2.1%	2.1%	2.1%	2.1%
17	5.7%	5.8%	5.8%	5.8%	5.8%
18	3.3%	3.2%	3.2%	3.2%	3.2%
20	2.1%	2.1%	2.1%	2.1%	2.1%
21	5.4%	5.3%	5.3%	5.3%	5.3%
22	2.1%	2.2%	2.3%	2.3%	2.3%
23	3.8%	4.1%	4.2%	4.2%	4.3%
24	0.5%	0.5%	0.4%	0.4%	0.4%
25	7.3%	7.1%	7.0%	7.0%	7.0%
26	4.5%	4.4%	4.4%	4.4%	4.4%
27	3.5%	3.6%	3.6%	3.7%	3.7%
28	6.9%	6.6%	6.6%	6.5%	6.5%
29	21.0%	20.1%	19.9%	19.7%	19.6%
30	0.5%	0.5%	0.5%	0.5%	0.5%
31	4.8%	4.7%	4.6%	4.6%	4.6%
34	0.5%	0.5%	0.5%	0.5%	0.5%
35	9.4%	9.0%	8.9%	8.8%	8.7%

Table N3. Peak Flows for Subwatersheds Based on Gage Station Flows					
Watershed	Peak Flow (cfs)				
	2-Year	10-Year	25-Year	50-Year	100-Year
1	18.7	40.3	53.5	64.0	75.3
2	51.8	112.0	148.5	177.8	209.3
3	27.9	58.0	76.1	90.4	105.7
4	26.6	55.9	73.5	87.5	102.5
5	58.2	121.9	160.5	190.9	223.7
6	10.4	21.4	28.0	33.2	38.8
7	20.3	46.6	62.8	76.1	90.5
8	21.4	44.8	58.9	70.1	82.1
9	27.6	57.3	75.2	89.3	104.4
10	31.2	64.8	85.1	101.0	118.2
11	16.8	36.2	48.0	57.4	67.6
12	41.2	97.7	132.7	161.8	193.5
13	33.1	76.8	103.8	126.0	150.1
14	35.2	73.0	95.8	113.8	133.1
15	24.1	54.7	73.5	88.9	105.5
16	11.1	23.5	31.1	37.0	43.4
17	29.9	65.3	86.8	104.1	122.7
18	17.1	36.5	48.2	57.6	67.7
20	11.0	23.6	31.2	37.3	43.9
21	28.3	60.4	79.9	95.5	112.2
22	10.8	25.1	34.0	41.2	49.1
23	20.0	46.5	62.8	76.3	90.9
24	2.5	5.1	6.7	8.0	9.3
25	38.3	80.2	105.6	125.6	147.2
26	23.4	50.1	66.3	79.1	93.0
27	18.1	40.7	54.6	65.8	78.0
28	35.7	74.8	98.5	117.2	137.3
29	109.4	227.0	298.1	353.9	414.1
30	2.5	5.5	7.3	8.8	10.4
31	24.9	52.7	69.5	82.9	97.3
34	2.6	5.4	7.1	8.4	9.8
35	48.8	101.2	132.9	157.8	184.6

APPENDIX O

1926 Aerial Map with Subwatersheds

1962 Aerial Map of Campus

1962 Aerial Map with Structures and Stream Defined

1962 Aerial Map with Subwatersheds

Land Use and CN for Subwatersheds for Different Time

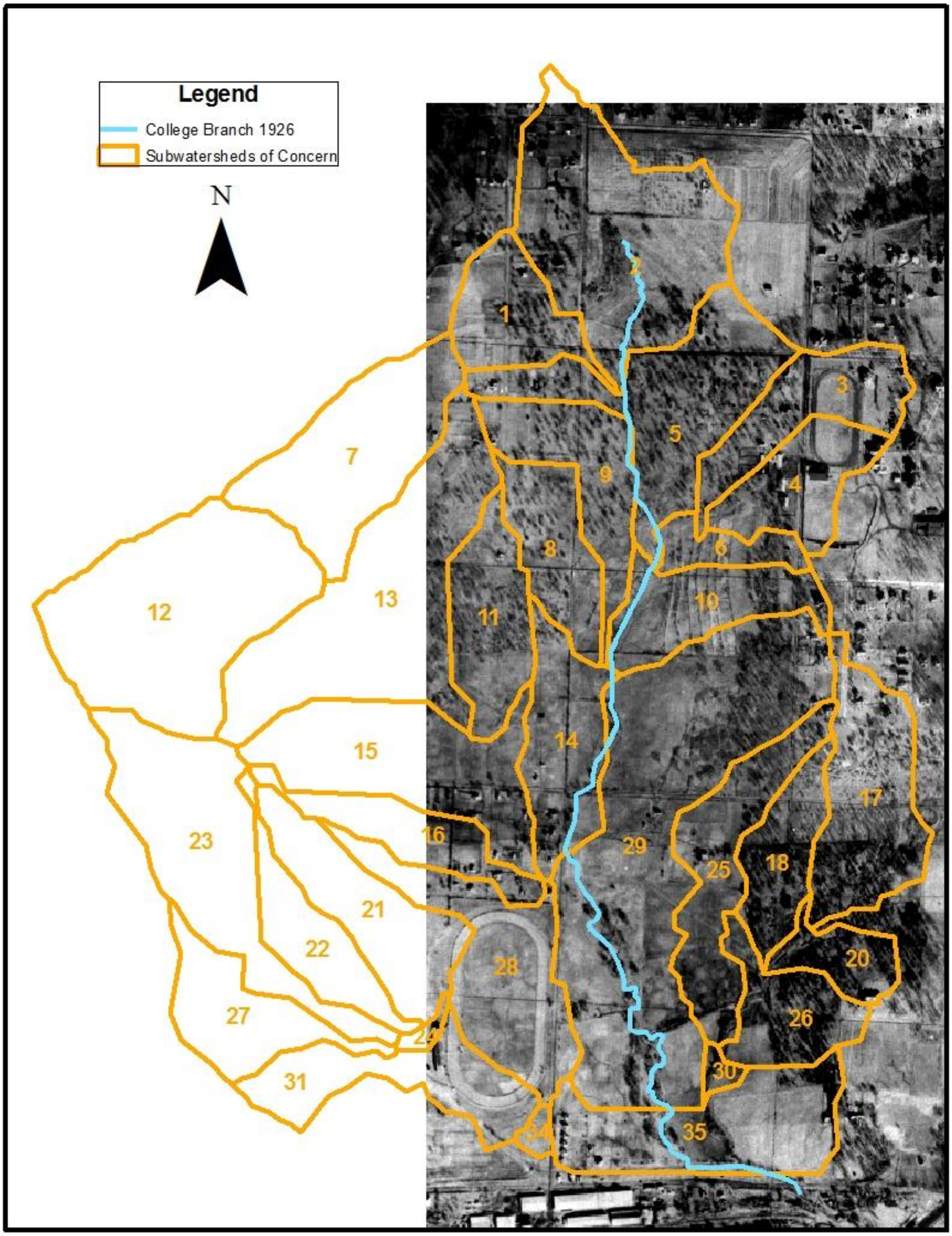

Figure O1. 1926 Aerial Map with Subwatersheds

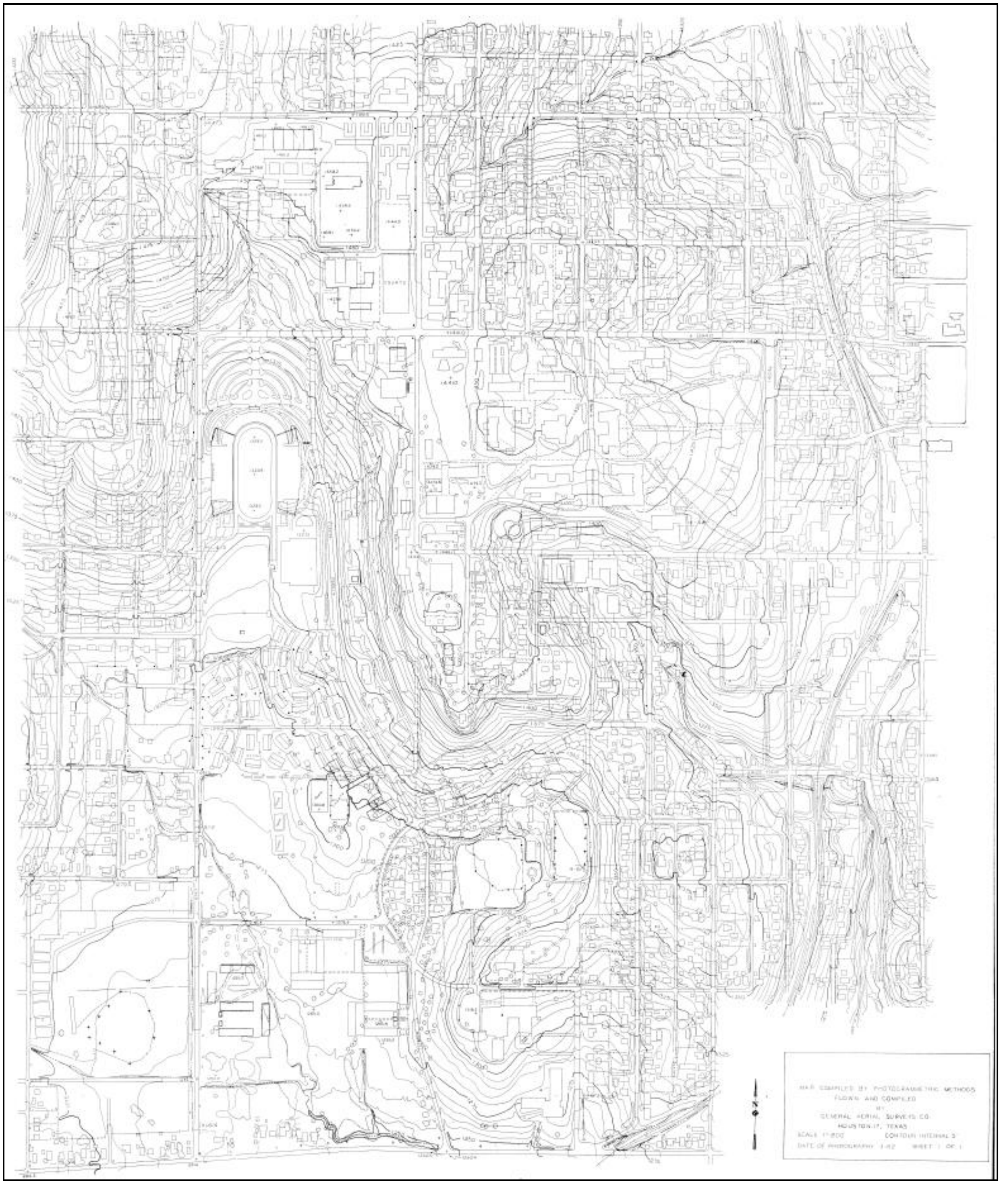

Figure O2. 1962 Aerial Map of Campus

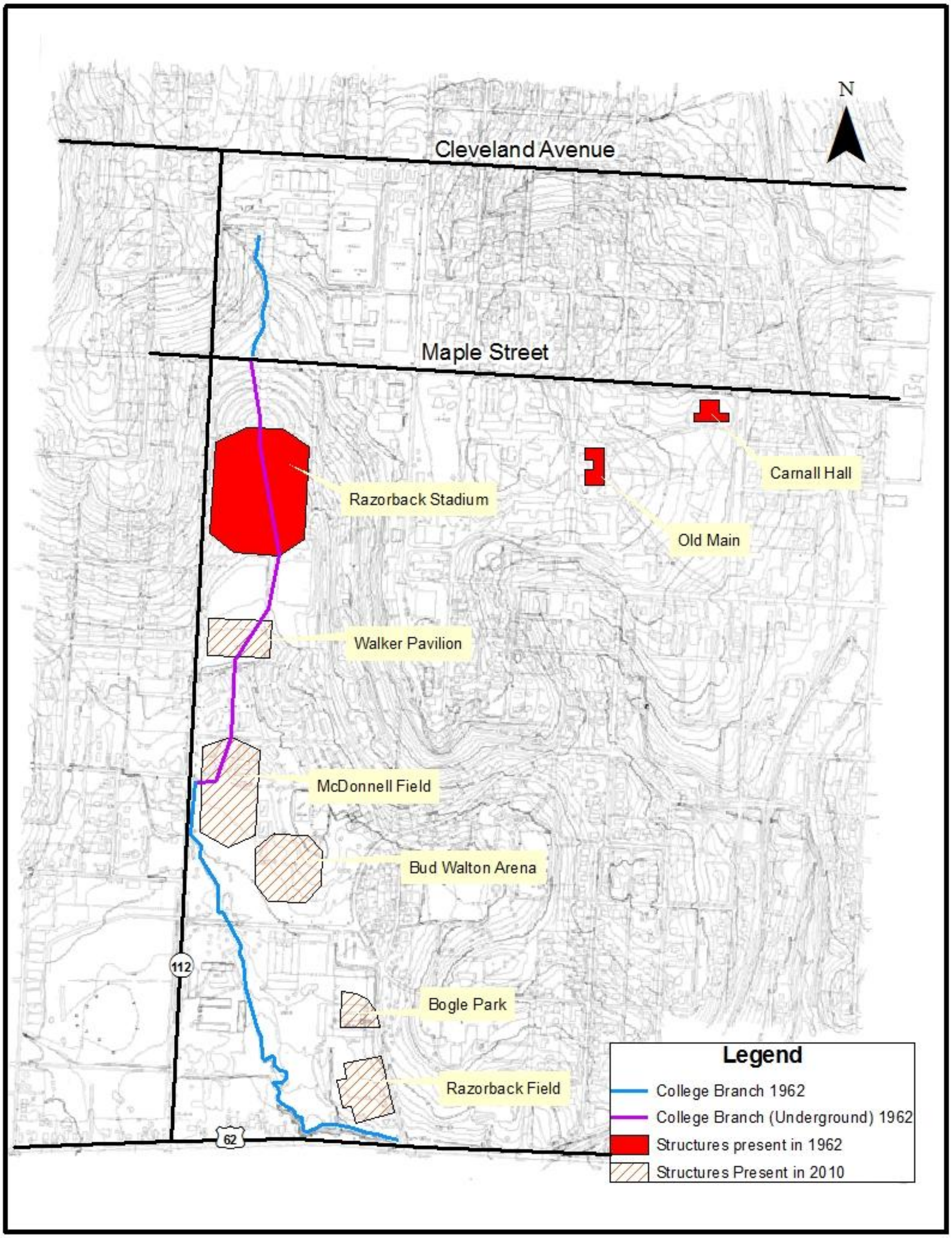

Figure O3. 1962 Aerial Map with Structures and Stream Defined

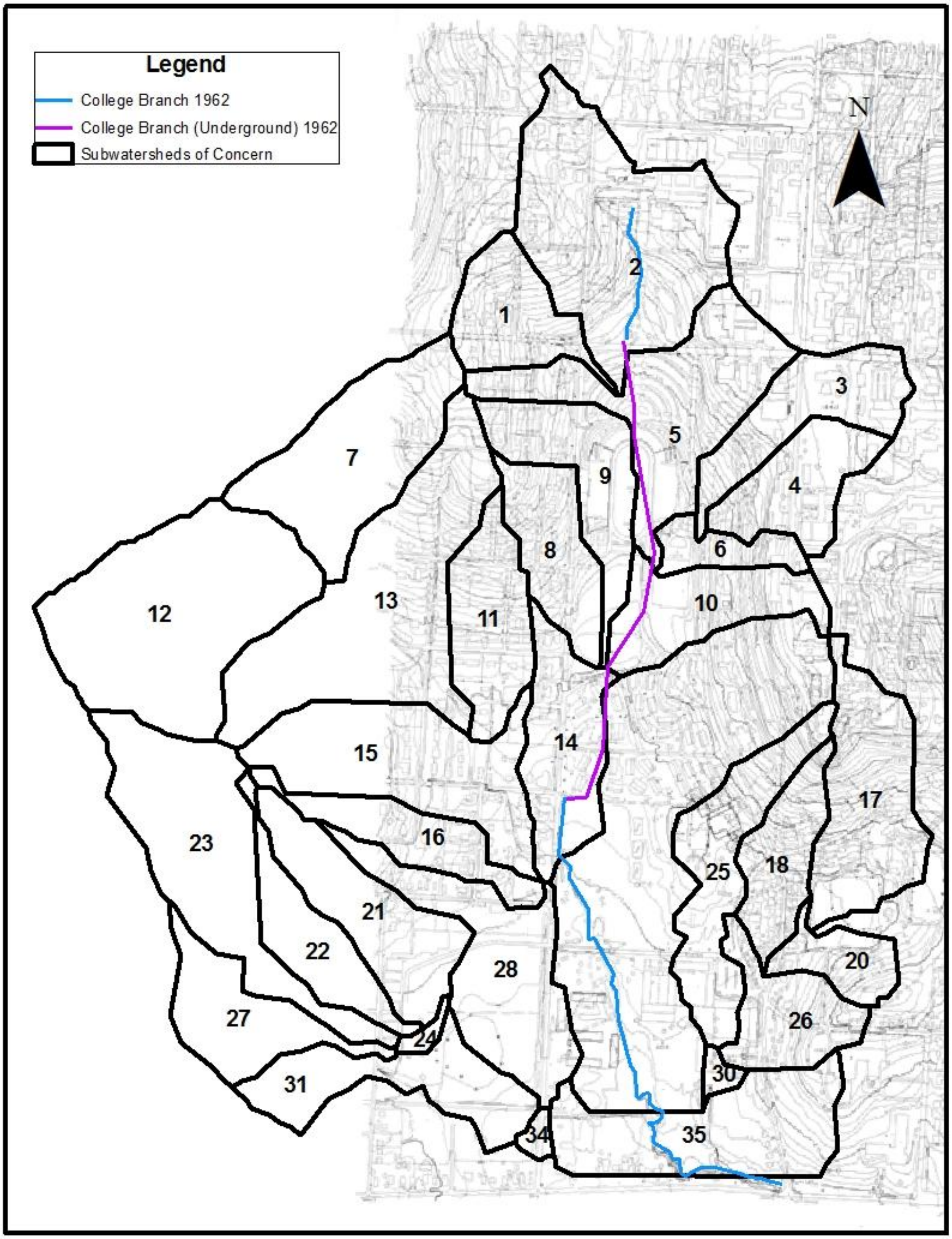

Figure O4. 1962 Aerial Map with Subwatersheds

Table O1. Land Uses and CN for Subwatersheds for Conditions at Different Periods of Time

Watershed	Hydrologic Soil Group	Pre-Development Conditions		1926 Conditions		1962 Conditions		Present Conditions	
		Land Use/ Land Cover	CN	Land Use/ Land Cover	CN	Land Use/ Land Cover	CN	Land Use/ Land Cover	CN
1	B & C	Forest	65	Pasture/Herbaceous	75	Herbaceous/Urban 1	78	Urban 1	94
2	B & C	Herbaceous/Forest	67	Pasture/Herbaceous	75	Herbaceous/Urban 1/3	83	Urban 1/3	94
3	B & C	Herbaceous	68	Pasture/Herbaceous	75	Urban 1/3	86	Urban 3	98
4	B & C	Herbaceous	68	Pasture/Herbaceous	75	Urban 1/3	86	Urban 3	97
5	C	Herbaceous	74	Pasture/Herbaceous	80	Urban 1/3	89	Urban 3	97
6	C	Herbaceous	74	Pasture/Herbaceous	80	Urban 1/3	89	Urban 3	99
7	C	Forest	72	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban/Forest	88
8	C	Herbaceous/Forest	73	Pasture/Herbaceous	80	Urban 1/3	89	Urban 1/3	97
9	C	Herbaceous/Forest	73	Pasture/Herbaceous	80	Urban 1/3	89	Urban 1/3	98
10	C	herbaceous	74	Pasture/Herbaceous	80	Urban 1/3	89	Urban 3	98
11	C	Forest	72	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban/Forest	94
12	C	Forest	72	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban/Forest	85
13	C & B/D	Herbaceous	74	Pasture/Herbaceous	79	Urban 1/3	88	Urban 3	87
14	C	Forest	72	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban 1	98
15	C	Herbaceous	74	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban 3	89
16	B/D & D	Forest	65	Pasture/Herbaceous	78	Herbaceous/Urban 1/3	85	Urban/Forest	96
17	B & C	Forest	72	Pasture/Herbaceous	75	Herbaceous/Urban 1	78	Urban 1	93
18	C	Herbaceous/Forest	73	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban 1/3	95
20	C	Herbaceous	74	Herbaceous	81	Herbaceous/Urban 1	82	Urban 3	95
21	C	Forest	72	Pasture/Herbaceous	80	Urban 1	83	Urban 1/3	95
22	C	Forest	72	Pasture/Herbaceous	80	Urban 1	83	Urban 1	87
23	C	Forest	72	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban 1	87
24	C	Forest	69	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban/Forest	99
25	B & C	Herbaceous	65	Pasture/Herbaceous	75	Herbaceous/Urban 1	78	Urban 3	97
26	C	Herbaceous	74	Herbaceous	81	Herbaceous/Urban 1	82	Urban 3	95
27	C	Forest	72	Pasture/Herbaceous	80	Urban 1	83	Urban 1/3	90
28	C	Herbaceous	74	Pasture/Herbaceous	80	Herbaceous/Urban 1	82	Urban 3	97
29	D	Herbaceous	85	Pasture/Herbaceous	87	Herbaceous/Urban 1	88	Urban 3	98
30	B/D	Herbaceous	74	Pasture/Herbaceous	78	Urban 1	81	Urban 1/3	93
31	C & D	Herbaceous	77	Pasture/Herbaceous	83	Herbaceous/Urban 1	85	Urban 3	96
34	D	Herbaceous	85	Pasture/Herbaceous	87	Urban 1/3	91	Urban 3	99
35	B/D & D	Herbaceous	74	Pasture/Herbaceous	78	Herbaceous/Urban 1/3	85	Urban 3	98

Appendix O2. Calculated Time of Concentrationsfor Subwatersheds in College Branch Watershed for Predevelopment Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	300	Forest	0.6	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.99
	Shallow Concentrated	825	Unpaved	N/A	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.08
2	Sheet	300	Herbaceous/Forest	0.5	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.41
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, Heavy brush	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
3	Sheet	300	Herbaceous	0.4	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00
	Shallow Concentrated	1515	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.31	0.18
4	Sheet	300	Herbaceous	0.4	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.82
	Shallow Concentrated	915	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.09
5	Channel	1080	Some weeds, Heavy brush	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
6	Sheet	300	Herbaceous	0.4	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.53
	Shallow Concentrated	600	Unpaved	N/A	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.95	0.06
7	Sheet	300	Forest	0.6	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.05
	Shallow Concentrated	1420	Unpaved	N/A	0.025	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	0.15
8	Sheet	300	Herbaceous/Forest	0.5	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.67
	Shallow Concentrated	1080	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.60	0.12
9	Sheet	300	Herbaceous/Forest	0.5	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.67
	Shallow Concentrated	1725	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.27	0.21
10	Channel	660	Some weeds, Heavy brush	0.06	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	1.93	0.09
11	Sheet	300	Forest	0.6	0.057	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.69
	Shallow Concentrated	1180	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.14
12	Sheet	300	Forest	0.6	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.86
	Shallow Concentrated	1350	Unpaved	N/A	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.67	0.14
13	Sheet	300	Herbaceous	0.4	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	1950	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.34	0.23
14	Sheet	300	Forest	0.6	0.047	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.75
	Shallow Concentrated	600	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.13
	Channel	670	Some weeds, Heavy brush	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
15	Sheet	300	Herbaceous	0.4	0.083	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.43
	Shallow Concentrated	1945	Unpaved	N/A	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.10	0.26
16	Sheet	300	Forest	0.6	0.070	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.64
	Shallow Concentrated	1600	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.18
17	Sheet	300	Forest	0.6	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.13
	Shallow Concentrated	1560	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.68	0.16
18	Sheet	300	Herbaceous/Forest	0.5	0.097	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.48
	Shallow Concentrated	1135	Unpaved	N/A	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.97	0.16
20	Sheet	300	Herbaceous	0.4	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	520	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.06
21	Sheet	300	Forest	0.6	0.090	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.58
	Shallow Concentrated	1450	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.18
22	Sheet	300	Forest	0.6	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.73
	Shallow Concentrated	1600	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.17
23	Sheet	300	Forest	0.6	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.13
	Shallow Concentrated	2500	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.46	0.28
24	Sheet	50	Forest	0.6	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.27
	Shallow Concentrated	80	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.51	0.01
25	Sheet	300	Herbaceous	0.4	0.077	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.44
	Shallow Concentrated	1960	Unpaved	N/A	0.014	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.93	0.28
26	Sheet	300	Herbaceous	0.4	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.76
	Shallow Concentrated	660	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	0.08
27	Sheet	300	Forest	0.6	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.86
	Shallow Concentrated	1500	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.50	0.28
28	Sheet	300	Herbaceous	0.4	0.063	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.48
	Shallow Concentrated	1960	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.46	0.37
29	Channel	2350	Some weeds, Heavy brush	0.06	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	0.94	0.69
30	Sheet	100	Herbaceous	0.04	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.07
	Shallow Concentrated	150	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.03
31	Sheet	300	Herbaceous	0.4	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.82
	Shallow Concentrated	1450	Unpaved/Paved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.47	0.27
34	Sheet	100	Herbaceous	0.4	0.005	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.55
	Shallow Concentrated	130	Unpaved	N/A	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00	0.04
35	Channel	990	Some weeds, Heavy brush	0.06	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.55	0.50

Table O3. Calculated NRCS Method Variables and Peak Flow for Storm Events in College Branch Watershed for Predevelopment Conditions

Watershed	Area (mi^2)	CN	S (in.)	Time of Conc. (hr)	2-Year Event					10-Year Event					25-Year Event					50-Year Event					100-Year Event				
					P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	0.016	65	5.38	1.07	4.1	0.26	1.1	244	4.2	6.2	0.17	2.5	266	10.4	7.1	0.15	3.2	271	13.5	8.0	0.13	3.9	275	16.8	8.9	0.12	4.6	279	20.3
2	0.050	67	5.04	1.63	4.1	0.25	1.2	205	12.0	6.2	0.16	2.6	222	29.1	7.1	0.14	3.3	225	37.3	8.0	0.13	4.1	229	46.2	8.9	0.11	4.8	231	55.3
3	0.019	68	4.71	1.19	4.1	0.23	1.3	242	5.7	6.2	0.15	2.8	261	13.5	7.1	0.13	3.5	265	17.2	8.0	0.12	4.2	269	21.2	8.9	0.11	5.0	272	25.3
4	0.016	68	4.71	0.91	4.1	0.23	1.3	273	5.6	6.2	0.15	2.8	294	13.1	7.1	0.13	3.5	299	16.8	8.0	0.12	4.2	303	20.6	8.9	0.11	5.0	306	24.6
5	0.035	74	3.51	0.15	4.1	0.17	1.7	577	33.8	6.2	0.11	3.4	596	70.0	7.1	0.10	4.1	600	86.8	8.0	0.09	4.9	600	103.5	8.9	0.08	5.7	600	120.6
6	0.007	74	3.51	0.58	4.1	0.17	1.7	362	4.2	6.2	0.11	3.4	383	9.0	7.1	0.10	4.1	388	11.3	8.0	0.09	4.9	388	13.4	8.9	0.08	5.7	388	15.6
7	0.032	72	3.89	1.21	4.1	0.19	1.5	250	12.2	6.2	0.13	3.2	265	26.8	7.1	0.11	3.9	269	33.7	8.0	0.10	4.7	271	40.7	8.9	0.09	5.5	271	47.6
8	0.016	73	3.70	0.78	4.1	0.18	1.6	310	8.0	6.2	0.12	3.3	329	17.2	7.1	0.10	4.0	334	21.6	8.0	0.09	4.8	335	26.0	8.9	0.08	5.6	335	30.3
9	0.020	73	3.70	0.88	4.1	0.18	1.6	291	9.1	6.2	0.12	3.3	306	19.4	7.1	0.10	4.0	313	24.6	8.0	0.09	4.8	314	29.5	8.9	0.08	5.6	314	34.4
10	0.018	74	3.51	0.09	4.1	0.17	1.7	629	19.2	6.2	0.11	3.4	646	39.5	7.1	0.10	4.1	650	49.0	8.0	0.09	4.9	650	58.4	8.9	0.08	5.7	650	68.1
11	0.019	72	3.89	0.83	4.1	0.19	1.5	298	8.6	6.2	0.13	3.2	317	18.9	7.1	0.11	3.9	321	23.8	8.0	0.10	4.7	324	28.8	8.9	0.09	5.5	324	33.7
12	0.052	72	3.89	1.00	4.1	0.19	1.5	268	21.2	6.2	0.13	3.2	284	46.3	7.1	0.11	3.9	288	58.2	8.0	0.10	4.7	290	70.2	8.9	0.09	5.5	290	82.2
13	0.051	74	3.57	0.91	4.1	0.17	1.6	289	24.2	6.2	0.12	3.3	304	51.3	7.1	0.10	4.1	308	64.1	8.0	0.09	4.9	308	76.6	8.9	0.08	5.7	308	89.2
14	0.021	72	3.89	1.04	4.1	0.19	1.5	264	8.3	6.2	0.13	3.2	280	18.2	7.1	0.11	3.9	284	22.9	8.0	0.10	4.7	286	27.6	8.9	0.09	5.5	286	32.3
15	0.034	74	3.51	0.69	4.1	0.17	1.7	334	19.0	6.2	0.11	3.4	353	40.4	7.1	0.10	4.1	358	50.4	8.0	0.09	4.9	358	60.1	8.9	0.08	5.7	358	70.1
16	0.014	65	5.38	0.82	4.1	0.26	1.1	278	4.3	6.2	0.17	2.5	304	10.8	7.1	0.15	3.2	311	14.1	8.0	0.13	3.9	316	17.6	8.9	0.12	4.6	320	21.2
17	0.027	72	3.89	1.29	4.1	0.19	1.5	243	10.1	6.2	0.13	3.2	258	22.1	7.1	0.11	3.9	262	27.9	8.0	0.10	4.7	264	33.7	8.9	0.09	5.5	264	39.4
18	0.014	73	3.70	0.64	4.1	0.18	1.6	343	7.8	6.2	0.12	3.3	363	16.7	7.1	0.10	4.0	369	21.0	8.0	0.09	4.8	370	25.2	8.9	0.08	5.6	370	29.4
20	0.009	74	3.51	0.74	4.1	0.17	1.7	323	4.7	6.2	0.11	3.4	341	9.9	7.1	0.10	4.1	345	12.3	8.0	0.09	4.9	345	14.7	8.9	0.08	5.7	345	17.1
21	0.023	72	3.89	0.75	4.1	0.19	1.5	314	10.9	6.2	0.13	3.2	335	24.0	7.1	0.11	3.9	340	30.1	8.0	0.10	4.7	343	36.5	8.9	0.09	5.5	343	42.7
22	0.014	72	3.89	0.90	4.1	0.19	1.5	285	6.3	6.2	0.13	3.2	303	13.8	7.1	0.11	3.9	307	17.3	8.0	0.10	4.7	310	21.0	8.9	0.09	5.5	310	24.6
23	0.037	72	3.89	1.42	4.1	0.19	1.5	233	13.1	6.2	0.13	3.2	247	28.6	7.1	0.11	3.9	250	35.9	8.0	0.10	4.7	252	43.4	8.9	0.09	5.5	252	50.7
24	0.001	69	4.49	0.29	4.1	0.22	1.3	464	0.9	6.2	0.14	2.9	492	2.0	7.1	0.13	3.6	499	2.5	8.0	0.11	4.3	505	3.1	8.9	0.10	5.1	509	3.7
25	0.024	65	5.38	0.73	4.1	0.26	1.1	296	7.6	6.2	0.17	2.5	324	19.2	7.1	0.15	3.2	331	25.0	8.0	0.13	3.9	337	31.2	8.9	0.12	4.6	341	37.6
26	0.015	74	3.51	0.84	4.1	0.17	1.7	301	7.5	6.2	0.11	3.4	318	16.0	7.1	0.10	4.1	322	19.9	8.0	0.09	4.9	322	23.8	8.9	0.08	5.7	322	27.7
27	0.017	72	3.89	1.14	4.1	0.19	1.5	256	6.8	6.2	0.13	3.2	271	14.9	7.1	0.11	3.9	275	18.8	8.0	0.10	4.7	277	22.7	8.9	0.09	5.5	277	26.6
28	0.029	74	3.51	0.85	4.1	0.17	1.7	299	14.7	6.2	0.11	3.4	316	31.2	7.1	0.10	4.1	320	39.0	8.0	0.09	4.9	320	46.5	8.9	0.08	5.7	320	54.1
29	0.083	85	1.76	0.69	4.1	0.09	2.5	358	75.7	6.2	0.06	4.5	358	133.4	7.1	0.05	5.3	358	158.8	8.0	0.04	6.2	358	184.5	8.9	0.04	7.1	358	210.4
30	0.002	74	3.51	0.10	4.1	0.17	1.7	629	1.8	6.2	0.11	3.4	646	3.7	7.1	0.10	4.1	650	4.6	8.0	0.09	4.9	650	5.5	8.9	0.08	5.7	650	6.4
31	0.020	77	2.99	1.09	4.1	0.15	1.9	271	10.4	6.2	0.10	3.7	282	20.9	7.1	0.08	4.5	282	25.4	8.0	0.07	5.3	282	30.1	8.9	0.07	6.1	282	34.9
34	0.001	85	1.76	0.59	4.1	0.09	2.5	384	1.5	6.2	0.06	4.5	384	2.6	7.1	0.05	5.3	384	3.1	8.0	0.04	6.2	384	3.6	8.9	0.04	7.1	384	4.1
35	0.030	74	3.51	0.50	4.1	0.17	1.7	392	19.6	6.2	0.11	3.4	415	41.6	7.1	0.10	4.1	420	51.8	8.0	0.09	4.9	420	61.8	8.9	0.08	5.7	420	72.0

Table O4. Calculated Time of Concentrationsfor Subwatersheds in College Branch Watershed for 1926 Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	300	Pasture/Herbaceous	0.2	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.41
	Shallow Concentrated	825	Unpaved	N/A	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.08
2	Sheet	300	Pasture/Herbaceous	0.2	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, Heavy brush	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
3	Sheet	300	Pasture/Herbaceous	0.2	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.58
	Shallow Concentrated	1515	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.31	0.18
4	Sheet	300	Pasture/Herbaceous	0.2	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	915	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.09
5	Channel	1080	Some weeds, Heavy brush	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
6	Sheet	300	Pasture/Herbaceous	0.2	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.30
	Shallow Concentrated	600	Unpaved	N/A	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.95	0.06
7	Sheet	300	Pasture/Herbaceous	0.2	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.44
	Shallow Concentrated	1420	Unpaved	N/A	0.025	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	0.15
8	Sheet	300	Pasture/Herbaceous	0.2	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.32
	Shallow Concentrated	1080	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.60	0.12
9	Sheet	300	Pasture/Herbaceous	0.2	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.32
	Shallow Concentrated	1725	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.27	0.21
10	Channel	660	Some weeds, light brush	0.05	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.57	0.07
11	Sheet	300	Pasture/Herbaceous	0.2	0.057	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.29
	Shallow Concentrated	1180	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.14
12	Sheet	300	Pasture/Herbaceous	0.2	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.36
	Shallow Concentrated	1350	Unpaved	N/A	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.67	0.14
13	Sheet	300	Pasture/Herbaceous	0.2	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.39
	Shallow Concentrated	1950	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.34	0.23
14	Sheet	300	Pasture/Herbaceous	0.2	0.047	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.31
	Shallow Concentrated	600	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.13
	Channel	670	Some weeds, Heavy brush	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
15	Sheet	300	Pasture/Herbaceous	0.2	0.083	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.25
	Shallow Concentrated	1945	Unpaved	N/A	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.10	0.26
16	Sheet	300	Pasture/Herbaceous	0.2	0.070	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.26
	Shallow Concentrated	1600	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.18
17	Sheet	300	Pasture/Herbaceous	0.2	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	1560	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.68	0.16
18	Sheet	300	Pasture/Herbaceous	0.2	0.097	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.23
	Shallow Concentrated	1135	Unpaved	N/A	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.97	0.16
20	Sheet	300	Herbaceous	0.4	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	520	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.06
21	Sheet	300	Pasture/Herbaceous	0.2	0.090	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.24
	Shallow Concentrated	1450	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.18
22	Sheet	300	Pasture/Herbaceous	0.2	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.30
	Shallow Concentrated	1600	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.17
23	Sheet	300	Pasture/Herbaceous	0.2	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	2500	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.46	0.28
24	Sheet	50	Forest	0.6	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.27
	Shallow Concentrated	80	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.51	0.01
25	Sheet	300	Pasture/Herbaceous	0.2	0.077	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.26
	Shallow Concentrated	1960	Unpaved	N/A	0.014	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.93	0.28
26	Sheet	300	Herbaceous	0.4	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.76
	Shallow Concentrated	660	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	0.08
27	Sheet	300	Pasture/Herbaceous	0.2	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.36
	Shallow Concentrated	1500	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.50	0.28
28	Sheet	300	Pasture/Herbaceous	0.2	0.063	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	1960	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.46	0.37
29	Channel	2350	Some weeds, light brush	0.05	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.26	0.52
30	Sheet	100	Pasture/Herbaceous	0.2	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.24
	Shallow Concentrated	150	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.03
31	Sheet	300	Pasture/Herbaceous	0.2	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	1450	Unpaved/Paved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.47	0.27
34	Sheet	100	Pasture/Herbaceous	0.2	0.005	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.32
	Shallow Concentrated	130	Unpaved	N/A	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00	0.04
35	Channel	990	Some weeds, light brush	0.05	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.73	0.37

Table O5. Calculated NRCS Method Variables and Peak Flow for Storm Events in College Branch Watershed for 1926 Conditions

Watershed	Area (mi^2)	CN	S (in.)	Time of Conc. (hr)	2-Year Event					10-Year Event					25-Year Event					50-Year Event					100-Year Event				
					P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	0.016	75	3.33	0.49	4.1	0.16	1.7	400	10.9	6.2	0.11	3.5	421	22.8	7.1	0.09	4.2	424	28.2	8.0	0.08	5.0	424	33.6	8.9	0.07	5.9	424	39.0
2	0.050	75	3.33	0.90	4.1	0.16	1.7	293	25.3	6.2	0.11	3.5	308	52.8	7.1	0.09	4.2	310	65.2	8.0	0.08	5.0	310	77.6	8.9	0.07	5.9	310	90.2
3	0.019	75	3.33	0.76	4.1	0.16	1.7	321	10.4	6.2	0.11	3.5	338	21.7	7.1	0.09	4.2	340	26.8	8.0	0.08	5.0	340	31.9	8.9	0.07	5.9	340	37.1
4	0.016	75	3.33	0.56	4.1	0.16	1.7	373	10.4	6.2	0.11	3.5	393	21.8	7.1	0.09	4.2	396	26.9	8.0	0.08	5.0	396	32.0	8.9	0.07	5.9	396	37.2
5	0.035	80	2.50	0.15	4.1	0.12	2.1	593	44.1	6.2	0.08	4.0	600	83.3	7.1	0.07	4.8	600	100.6	8.0	0.06	5.6	600	118.2	8.9	0.06	6.5	600	136.0
6	0.007	80	2.50	0.36	4.1	0.12	2.1	469	7.0	6.2	0.08	4.0	478	13.3	7.1	0.07	4.8	478	16.1	8.0	0.06	5.6	478	18.9	8.9	0.06	6.5	478	21.7
7	0.032	80	2.50	0.59	4.1	0.12	2.1	376	25.5	6.2	0.08	4.0	384	48.7	7.1	0.07	4.8	384	58.8	8.0	0.06	5.6	384	69.1	8.9	0.06	6.5	384	79.5
8	0.016	80	2.50	0.44	4.1	0.12	2.1	435	14.9	6.2	0.08	4.0	444	28.3	7.1	0.07	4.8	444	34.2	8.0	0.06	5.6	444	40.2	8.9	0.06	6.5	444	46.3
9	0.020	80	2.50	0.53	4.1	0.12	2.1	400	16.6	6.2	0.08	4.0	408	31.6	7.1	0.07	4.8	408	38.1	8.0	0.06	5.6	408	44.8	8.9	0.06	6.5	408	51.6
10	0.018	80	2.50	0.07	4.1	0.12	2.1	650	25.2	6.2	0.08	4.0	650	47.0	7.1	0.07	4.8	650	56.8	8.0	0.06	5.6	650	66.7	8.9	0.06	6.5	650	76.8
11	0.019	80	2.50	0.43	4.1	0.12	2.1	439	17.6	6.2	0.08	4.0	448	33.6	7.1	0.07	4.8	448	40.6	8.0	0.06	5.6	448	47.7	8.9	0.06	6.5	448	54.8
12	0.052	80	2.50	0.50	4.1	0.12	2.1	411	45.1	6.2	0.08	4.0	420	85.9	7.1	0.07	4.8	420	103.7	8.0	0.06	5.6	420	121.9	8.9	0.06	6.5	420	140.3
13	0.051	79	2.69	0.62	4.1	0.13	2.0	365	37.7	6.2	0.09	3.8	375	73.2	7.1	0.08	4.7	375	88.8	8.0	0.07	5.5	375	104.6	8.9	0.06	6.3	375	120.7
14	0.021	80	2.50	0.60	4.1	0.12	2.1	372	16.2	6.2	0.08	4.0	380	30.9	7.1	0.07	4.8	380	37.4	8.0	0.06	5.6	380	43.9	8.9	0.06	6.5	380	50.6
15	0.034	80	2.50	0.50	4.1	0.12	2.1	411	29.8	6.2	0.08	4.0	420	56.8	7.1	0.07	4.8	420	68.6	8.0	0.06	5.6	420	80.6	8.9	0.06	6.5	420	92.7
16	0.014	78	2.78	0.45	4.1	0.14	2.0	425	12.1	6.2	0.09	3.8	440	23.8	7.1	0.08	4.6	440	28.9	8.0	0.07	5.4	440	34.1	8.9	0.06	6.3	440	39.3
17	0.027	75	3.33	0.63	4.1	0.16	1.7	351	16.6	6.2	0.11	3.5	370	34.7	7.1	0.09	4.2	373	43.0	8.0	0.08	5.0	373	51.1	8.9	0.07	5.9	373	59.4
18	0.014	80	2.50	0.39	4.1	0.12	2.1	455	13.7	6.2	0.08	4.0	465	26.1	7.1	0.07	4.8	465	31.5	8.0	0.06	5.6	465	37.0	8.9	0.06	6.5	465	42.6
20	0.009	81	2.35	0.74	4.1	0.11	2.2	340	6.5	6.2	0.08	4.1	345	12.1	7.1	0.07	4.9	345	14.6	8.0	0.06	5.7	345	17.1	8.9	0.05	6.6	345	19.7
21	0.023	80	2.50	0.42	4.1	0.12	2.1	443	21.3	6.2	0.08	4.0	452	40.6	7.1	0.07	4.8	452	49.0	8.0	0.06	5.6	452	57.6	8.9	0.06	6.5	452	66.3
22	0.014	80	2.50	0.48	4.1	0.12	2.1	419	12.8	6.2	0.08	4.0	428	24.5	7.1	0.07	4.8	428	29.5	8.0	0.06	5.6	428	34.7	8.9	0.06	6.5	428	39.9
23	0.037	80	2.50	0.75	4.1	0.12	2.1	336	26.2	6.2	0.08	4.0	343	49.8	7.1	0.07	4.8	343	60.2	8.0	0.06	5.6	343	70.7	8.9	0.06	6.5	343	81.4
24	0.001	80	2.50	0.29	4.1	0.12	2.1	501	1.5	6.2	0.08	4.0	510	2.9	7.1	0.07	4.8	510	3.5	8.0	0.06	5.6	510	4.1	8.9	0.06	6.5	510	4.7
25	0.024	75	3.33	0.54	4.1	0.16	1.7	381	15.8	6.2	0.11	3.5	401	32.9	7.1	0.09	4.2	404	40.7	8.0	0.08	5.0	404	48.4	8.9	0.07	5.9	404	56.3
26	0.015	81	2.35	0.84	4.1	0.11	2.2	318	10.5	6.2	0.08	4.1	322	19.6	7.1	0.07	4.9	322	23.6	8.0	0.06	5.7	322	27.7	8.9	0.05	6.6	322	31.8
27	0.017	80	2.50	0.63	4.1	0.12	2.1	365	13.5	6.2	0.08	4.0	373	25.8	7.1	0.07	4.8	373	31.2	8.0	0.06	5.6	373	36.6	8.9	0.06	6.5	373	42.1
28	0.029	80	2.50	0.65	4.1	0.12	2.1	360	22.5	6.2	0.08	4.0	368	43.0	7.1	0.07	4.8	368	51.9	8.0	0.06	5.6	368	61.0	8.9	0.06	6.5	368	70.2
29	0.083	87	1.56	0.52	4.1	0.08	2.7	412	91.7	6.2	0.05	4.7	412	159.1	7.1	0.04	5.5	412	188.6	8.0	0.04	6.4	412	218.4	8.9	0.04	7.3	412	248.4
30	0.002	78	2.78	0.27	4.1	0.14	2.0	639	2.2	6.2	0.09	3.8	650	4.2	7.1	0.08	4.6	650	5.1	8.0	0.07	5.4	650	6.1	8.9	0.06	6.3	650	7.0
31	0.020	83	2.01	0.74	4.1	0.10	2.4	282	13.7	6.2	0.06	4.3	282	24.6	7.1	0.06	5.2	282	29.4	8.0	0.05	6.0	282	34.3	8.9	0.05	6.9	282	39.2
34	0.001	87	1.56	0.35	4.1	0.08	2.7	483	1.9	6.2	0.05	4.7	483	3.4	7.1	0.04	5.5	483	4.0	8.0	0.04	6.4	483	4.6	8.9	0.04	7.3	483	5.2
35	0.030	78	2.78	0.37	4.1	0.14	2.0	458	27.2	6.2	0.09	3.8	458	51.8	7.1	0.08	4.6	458	62.9	8.0	0.07	5.4	458	74.2	8.9	0.06	6.3	458	85.7

Table O6. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for 1962 Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	300	Herbaceous/Urban 1	0.15	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.33
	Shallow Concentrated	825	Unpaved	N/A	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.08
2	Sheet	300	Herbaceous/Urban 1/3	0.1	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.39
	Shallow Concentrated	680	Unpaved	N/A	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.47	0.08
	Channel	806	Some weeds, light brush	0.05	0.019	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	3.19	0.07
	Pipe	70	Concrete Pipe	0.011	0.008	4.1	3' by 3'	3' by 3'	N/A	N/A	3.00	5.00	0.60	8.584	0.002
3	Sheet	300	Urban 1/3	0.05	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19
	Shallow Concentrated	1515	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.31	0.18
4	Sheet	300	Urban 1/3	0.05	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.16
	Shallow Concentrated	915	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.09
5	Pipe	1100	Concrete Pipe	0.011	0.006	4.1	1	0.5	0.1	1.29	0.04	0.64	0.06	1.67	0.18
6	Sheet	300	Urban 1/3	0.1	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10
	Shallow Concentrated	600	Unpaved	N/A	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.95	0.06
7	Sheet	300	Herbaceous/Urban 1	0.15	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.35
	Shallow Concentrated	1420	Unpaved	N/A	0.025	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	0.15
8	Sheet	300	Urban 1/3	0.05	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.11
	Shallow Concentrated	1080	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.60	0.12
9	Sheet	300	Urban 1/3	0.05	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.11
	Shallow Concentrated	1725	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.27	0.21
10	Pipe	805	Concrete Pipe	0.011	0.009	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	4.11	0.05
11	Sheet	300	Herbaceous/Urban 1	0.15	0.057	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.23
	Shallow Concentrated	1180	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.14
12	Sheet	300	Herbaceous/Urban 1	0.15	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	1350	Unpaved	N/A	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.67	0.14
13	Sheet	300	Urban 1/3	0.05	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.13
	Shallow Concentrated	1950	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.34	0.23
14	Channel	500	Some weeds, light brush	0.05	0.006	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.78	0.08
	Pipe	900	Concrete Pipe	0.011	0.003	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	2.45	0.10
15	Sheet	300	Herbaceous/Urban 1	0.15	0.083	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.20
	Shallow Concentrated	1945	Unpaved	N/A	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.10	0.26
16	Sheet	300	Herbaceous/Urban 1/3	0.1	0.070	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.15
	Shallow Concentrated	1600	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.18
17	Sheet	300	Herbaceous/Urban 1	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	1560	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.68	0.16
18	Sheet	300	Herbaceous/Urban 1/3	0.1	0.097	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.13
	Shallow Concentrated	1135	Unpaved	N/A	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.97	0.16
20	Sheet	300	Herbaceous/Urban 1	0.15	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.31
	Shallow Concentrated	520	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.06
21	Sheet	300	Urban 1	0.07	0.090	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10
	Shallow Concentrated	1450	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.18
22	Sheet	300	Urban 1	0.07	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.13
	Shallow Concentrated	1600	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.17
23	Sheet	300	Herbaceous/Urban 1	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	2500	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.46	0.28
24	Sheet	50	Herbaceous/Urban 1	0.15	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.09
	Shallow Concentrated	80	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.51	0.01
25	Sheet	300	Herbaceous/Urban 1	0.15	0.077	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.20
	Shallow Concentrated	1960	Unpaved	N/A	0.014	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.93	0.28
26	Sheet	300	Herbaceous/Urban 1	0.15	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.35
	Shallow Concentrated	660	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	0.08
27	Sheet	300	Urban 1	0.07	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.15
	Shallow Concentrated	1500	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.50	0.28
28	Sheet	300	Herbaceous/Urban 1	0.15	0.063	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.22
	Shallow Concentrated	1960	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.46	0.37
29	Channel	2350	Some weeds, light brush	0.05	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.26	0.52
30	Sheet	100	Urban 1	0.07	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10
	Shallow Concentrated	150	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.03
31	Sheet	300	Herbaceous/Urban 1	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	1450	Unpaved/Paved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.47	0.27
34	Sheet	100	Urban 1/3	0.1	0.005	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.10
	Shallow Concentrated	130	Unpaved	N/A	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00	0.04
35	Channel	990	Some weeds, light brush	0.05	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.73	0.37

Appendix O7. Calculated NRCS Method Variables and Peak Flow for Storm Events in College Branch Watershed for 1962 Conditions

Watershed	Area (mi^2)	CN	S (in.)	Time of Conc. (hr)	2-Year Event					10-Year Event					25-Year Event				
					P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	0.016	78	2.90	0.41	4.1	0.14	1.9	417	12.6	6.2	0.09	3.7	432	25.1	7.1	0.08	4.5	432	30.6
2	0.050	83	2.11	0.54	4.1	0.10	2.3	404	46.9	6.2	0.07	4.2	404	85.0	7.1	0.06	5.1	404	101.8
3	0.019	86	1.63	0.37	4.1	0.1	2.6	474	23.3	6.2	0.05	4.6	474	40.6	7.1	0.05	5.5	474	48.2
4	0.016	86	1.63	0.25	4.1	0.08	2.6	528	22.3	6.2	0.05	4.6	528	39.0	7.1	0.05	5.5	528	46.3
5	0.035	89	1.30	0.18	4.1	0.06	2.9	570	57.3	6.2	0.04	4.9	570	97.3	7.1	0.04	5.7	570	114.8
6	0.007	89	1.30	0.16	4.1	0.06	2.9	590	11.9	6.2	0.04	4.9	590	20.2	7.1	0.04	5.7	590	23.8
7	0.032	82	2.20	0.50	4.1	0.11	2.3	417	30.5	6.2	0.07	4.2	420	56.0	7.1	0.06	5.0	420	67.3
8	0.016	89	1.24	0.22	4.1	0.06	2.9	541	25.4	6.2	0.04	4.9	541	42.9	7.1	0.03	5.8	541	50.6
9	0.020	89	1.24	0.32	4.1	0.06	2.9	496	28.2	6.2	0.04	4.9	496	47.7	7.1	0.03	5.8	496	56.2
10	0.018	89	1.24	0.05	4.1	0.06	2.9	650	34.6	6.2	0.04	4.9	650	58.5	7.1	0.03	5.8	650	68.9
11	0.019	82	2.20	0.37	4.1	0.11	2.3	471	20.4	6.2	0.07	4.2	474	37.4	7.1	0.06	5.0	474	44.9
12	0.052	82	2.20	0.42	4.1	0.11	2.3	449	53.0	6.2	0.07	4.2	452	97.3	7.1	0.06	5.0	452	116.8
13	0.051	88	1.42	0.36	4.1	0.07	2.8	478	67.7	6.2	0.05	4.8	478	116.1	7.1	0.04	5.6	478	137.2
14	0.021	82	2.20	0.18	4.1	0.11	2.3	568	26.7	6.2	0.07	4.2	570	48.9	7.1	0.06	5.0	570	58.7
15	0.034	82	2.20	0.45	4.1	0.11	2.3	437	34.1	6.2	0.07	4.2	440	62.6	7.1	0.06	5.0	440	75.2
16	0.014	85	1.79	0.34	4.1	0.09	2.5	487	17.6	6.2	0.06	4.5	487	31.1	7.1	0.05	5.3	487	37.0
17	0.027	78	2.82	0.54	4.1	0.14	2.0	390	20.9	6.2	0.09	3.8	404	41.2	7.1	0.08	4.6	404	50.1
18	0.014	82	2.20	0.29	4.1	0.11	2.3	507	16.4	6.2	0.07	4.2	510	30.1	7.1	0.06	5.0	510	36.2
20	0.009	82	2.20	0.37	4.1	0.11	2.3	471	9.3	6.2	0.07	4.2	474	17.1	7.1	0.06	5.0	474	20.5
21	0.023	83	2.05	0.28	4.1	0.10	2.4	514	27.6	6.2	0.07	4.3	514	49.8	7.1	0.06	5.1	514	59.6
22	0.014	83	2.05	0.30	4.1	0.10	2.4	505	17.3	6.2	0.07	4.3	505	31.1	7.1	0.06	5.1	505	37.3
23	0.037	82	2.20	0.66	4.1	0.11	2.3	363	30.5	6.2	0.07	4.2	365	55.8	7.1	0.06	5.0	365	67.0
24	0.001	82	2.20	0.11	4.1	0.11	2.3	638	2.1	6.2	0.07	4.2	640	3.8	7.1	0.06	5.0	640	4.5
25	0.024	78	2.82	0.49	4.1	0.14	2.0	409	19.1	6.2	0.09	3.8	424	37.9	7.1	0.08	4.6	424	46.0
26	0.015	82	2.20	0.42	4.1	0.11	2.3	449	15.4	6.2	0.07	4.2	452	28.3	7.1	0.06	5.0	452	33.9
27	0.017	83	2.05	0.43	4.1	0.10	2.4	448	18.6	6.2	0.07	4.3	448	33.4	7.1	0.06	5.1	448	40.1
28	0.029	82	2.20	0.59	4.1	0.11	2.3	381	25.7	6.2	0.07	4.2	384	47.2	7.1	0.06	5.0	384	56.7
29	0.083	88	1.36	0.52	4.1	0.07	2.8	412	96.4	6.2	0.04	4.8	412	164.7	7.1	0.04	5.7	412	194.5
30	0.002	81	2.35	0.14	4.1	0.11	2.2	605	2.3	6.2	0.08	4.1	610	4.3	7.1	0.07	4.9	610	5.1
31	0.020	85	1.76	0.65	4.1	0.09	2.5	368	19.0	6.2	0.06	4.5	368	33.5	7.1	0.05	5.3	368	39.8
34	0.001	91	0.99	0.14	4.1	0.05	3.1	610	2.8	6.2	0.03	5.2	610	4.7	7.1	0.03	6.0	610	5.5
35	0.030	85	1.79	0.37	4.1	0.09	2.5	474	35.8	6.2	0.06	4.5	474	63.3	7.1	0.05	5.3	474	75.4

Watershed	50-Year Event					100-Year Event				
	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	8.0	0.07	5.3	432	36.2	8.9	0.07	6.2	432	41.8
2	8.0	0.05	5.9	404	119.0	8.9	0.05	6.8	404	136.2
3	8.0	0.04	6.3	474	55.9	8.9	0.04	7.2	474	63.6
4	8.0	0.04	6.3	528	53.6	8.9	0.04	7.2	528	61.1
5	8.0	0.03	6.6	570	132.3	8.9	0.03	7.5	570	150.0
6	8.0	0.03	6.6	590	27.5	8.9	0.03	7.5	590	31.1
7	8.0	0.05	5.9	420	78.7	8.9	0.05	6.7	420	90.2
8	8.0	0.03	6.7	541	58.3	8.9	0.03	7.6	541	66.0
9	8.0	0.03	6.7	496	64.7	8.9	0.03	7.6	496	73.3
10	8.0	0.03	6.7	650	79.3	8.9	0.03	7.6	650	89.8
11	8.0	0.05	5.9	474	52.5	8.9	0.05	6.7	474	60.2
12	8.0	0.05	5.9	452	136.7	8.9	0.05	6.7	452	156.7
13	8.0	0.04	6.5	478	158.5	8.9	0.03	7.4	478	179.9
14	8.0	0.05	5.9	570	68.7	8.9	0.05	6.7	570	78.7
15	8.0	0.05	5.9	440	87.9	8.9	0.05	6.7	440	100.8
16	8.0	0.04	6.2	487	43.1	8.9	0.04	7.1	487	49.1
17	8.0	0.07	5.4	404	59.2	8.9	0.06	6.2	404	68.4
18	8.0	0.05	5.9	510	42.3	8.9	0.05	6.7	510	48.5
20	8.0	0.05	5.9	474	24.0	8.9	0.05	6.7	474	27.5
21	8.0	0.05	6.0	514	69.6	8.9	0.05	6.8	514	79.6
22	8.0	0.05	6.0	505	43.5	8.9	0.05	6.8	505	49.8
23	8.0	0.05	5.9	365	78.4	8.9	0.05	6.7	365	89.9
24	8.0	0.05	5.9	640	5.3	8.9	0.05	6.7	640	6.1
25	8.0	0.07	5.4	424	54.3	8.9	0.06	6.2	424	62.8
26	8.0	0.05	5.9	452	39.7	8.9	0.05	6.7	452	45.5
27	8.0	0.05	6.0	448	46.7	8.9	0.05	6.8	448	53.5
28	8.0	0.05	5.9	384	66.3	8.9	0.05	6.7	384	76.1
29	8.0	0.03	6.6	412	224.5	8.9	0.03	7.4	412	254.6
30	8.0	0.06	5.7	610	6.0	8.9	0.05	6.6	610	6.9
31	8.0	0.04	6.2	368	46.3	8.9	0.04	7.1	368	52.8
34	8.0	0.02	6.9	610	6.3	8.9	0.02	7.8	610	7.1
35	8.0	0.04	6.2	474	87.7	8.9	0.04	7.1	474	100.0

Table O8. Calculated Time of Concentrations for College Branch Watershed for Predevelopment Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
2	Sheet	300	Herbaceous/Forest	0.5	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.41
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Light brush and trees	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
5	Channel	1080	Light brush and trees	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
10	Channel	660	Light brush and trees	0.06	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	1.93	0.09
14	Channel	670	Light brush and trees	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
29	Channel	2350	Light brush and trees	0.06	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	0.94	0.69
35	Channel	990	Light brush and trees	0.06	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.55	0.50
TOTAL		7820													3.2

Table O9. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for 1926 Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
2	Sheet	300	Pasture/Herbaceous	0.2	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.68
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, Heavy brush	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
5	Channel	1080	Some weeds, Heavy brush	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
10	Channel	660	Some weeds, light brush	0.045	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.57	0.07
14	Channel	670	Some weeds, Heavy brush	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
29	Channel	2350	Some weeds, light brush	0.045	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.26	0.52
35	Channel	990	Some weeds, light brush	0.045	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.73	0.37
TOTAL		7820													2.2

Table O10. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for 1962 Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
2	Sheet	300	Herbaceous/Urban 1/3	0.1	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.39
	allow Concentrat	680	Unpaved	N/A	0.024	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.47	0.08
	Channel	806	Some weeds, light brush	0.045	0.019	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	3.19	0.07
	Pipe	70	Concrete Pipe	0.011	0.008	4.1	3' by 3'	3' by 3'	N/A	N/A	3.00	5.00	0.60	8.619	0.002
5	Pipe	1100	Concrete Pipe	0.011	0.006	4.1	1	0.5	0.1	1.29	0.04	0.64	0.06	1.67	0.18
10	Pipe	650	Concrete Pipe	0.011	0.009	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	4.11	0.04
14	Pipe	900	Concrete Pipe	0.011	0.003	4.1	1.5	0.75	0.3	1.85	0.25	1.39	0.18	2.45	0.10
	Channel	300	Some weeds, light brush	0.045	0.010	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	2.30	0.04
29	Channel	1780	Some weeds, light brush	0.045	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.44	0.34
35	Channel	960	Some weeds, light brush	0.045	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.75	0.36
TOTAL		7546													1.14

Table O11. Calculated Peak Flows for Entire Watershed of Concern for Predevelopment Conditions

Length (ft)	7820				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	73				
S (in.)	3.67				
Time of Conc. (hr)	3.23				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	1.6	3.3	4.0	4.8	5.6
Ia/P	0.18	0.12	0.10	0.09	0.08
q_{um} (csm/in)	144	151	153	154	154
q_p (cfs)	178	378	473	569	664

Table O12. Calculated Peak Flows for Entire Watershed of Concern for 1926 Conditions

Length (ft)	7820				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	80				
S (in.)	2.55				
Time of Conc. (hr)	2.18				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	2.1	3.9	4.7	5.6	6.4
Ia/P	0.12	0.08	0.07	0.06	0.06
q_{um} (csm/in)	190	193	193	193	193
q_p (cfs)	305	580	702	825	950

Table O13. Calculated Peak Flows for Entire Watershed of Concern for 1962 Conditions

Length (ft)	7546				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	84				
S (in.)	1.90				
Time of Conc. (hr)	1.14				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	2.5	4.4	5.2	6.1	7.0
Ia/P	0.09	0.06	0.05	0.05	0.04
q_{um} (csm/in)	277	277	277	277	277
q_p (cfs)	523	931	1111	1294	1478

Table O14. Land Uses and CN for Subwatersheds for Conditions at Various Development Conditions

Watershed	Hydrologic Soil Group	Pre-Development Conditions		Residential (1/2 acre) Conditions		Residential (1/8 acre) Conditions		Present Conditions	
		Land Use/ Land Cover	CN	Land Use/ Land Cover	CN	Land Use/ Land Cover	CN	Land Use/ Land Cover	CN
1	B & C	Forest	65	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 1	94
2	B & C	Herbaceous/Forest	67	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 1/3	94
3	B & C	Herbaceous	68	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 3	98
4	B & C	Herbaceous	68	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 3	97
5	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	97
6	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	99
7	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban/Forest	88
8	C	Herbaceous/Forest	73	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1/3	97
9	C	Herbaceous/Forest	73	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1/3	98
10	C	herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	98
11	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban/Forest	94
12	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban/Forest	85
13	C & B/D	Herbaceous	74	Resid. (1/2 ac)/Forest	76	Resid. (1/8) ac/Forest	82	Urban 3	87
14	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1	98
15	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	89
16	B/D & D	Forest	65	Resid. (1/2 ac)/Forest	76	Resid. (1/8) ac/Forest	81	Urban/Forest	96
17	B & C	Forest	72	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 1	93
18	C	Herbaceous/Forest	73	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1/3	95
20	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	95
21	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1/3	95
22	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1	87
23	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1	87
24	C	Forest	69	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban/Forest	99
25	B & C	Herbaceous	65	Resid. (1/2 ac)/Forest	73	Resid. (1/8) ac/Forest	79	Urban 3	97
26	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	95
27	C	Forest	72	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 1/3	90
28	C	Herbaceous	74	Resid. (1/2 ac)/Forest	78	Resid. (1/8) ac/Forest	83	Urban 3	97
29	D	Herbaceous	85	Resid. (1/2 ac)/Forest	84	Resid. (1/8) ac/Forest	87	Urban 3	98
30	B/D	Herbaceous	74	Resid. (1/2 ac)/Forest	76	Resid. (1/8) ac/Forest	81	Urban 1/3	93
31	C & D	Herbaceous	77	Resid. (1/2 ac)/Forest	81	Resid. (1/8) ac/Forest	85	Urban 3	96
34	D	Herbaceous	85	Resid. (1/2 ac)/Forest	84	Resid. (1/8) ac/Forest	87	Urban 3	99
35	B/D & D	Herbaceous	74	Resid. (1/2 ac)/Forest	76	Resid. (1/8) ac/Forest	81	Urban 3	98

Table O15. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for Residential (1/2 acre lots) Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.49
	Shallow Concentrated	825	Unpaved	N/A	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.08
2	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.81
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, heavy brush	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
3	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.69
	Shallow Concentrated	1515	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.31	0.18
4	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.56
	Shallow Concentrated	915	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.09
5	Channel	1080	Some weeds, heavy brush	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
6	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.36
	Shallow Concentrated	600	Unpaved	N/A	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.95	0.06
7	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.52
	Shallow Concentrated	1420	Unpaved	N/A	0.025	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	0.15
8	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.38
	Shallow Concentrated	1080	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.60	0.12
9	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.38
	Shallow Concentrated	1725	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.27	0.21
10	Channel	660	Some weeds, heavy brush	0.06	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	1.93	0.09
11	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.057	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.34
	Shallow Concentrated	1180	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.14
12	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.43
	Shallow Concentrated	1350	Unpaved	N/A	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.67	0.14
13	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	1950	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.34	0.23
14	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.047	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	600	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.13
	Channel	670	Some weeds, heavy brush	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
15	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.083	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.30
	Shallow Concentrated	1945	Unpaved	N/A	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.10	0.26
16	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.070	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.32
	Shallow Concentrated	1600	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.18
17	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.56
	Shallow Concentrated	1560	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.68	0.16
18	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.097	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	1135	Unpaved	N/A	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.97	0.16
20	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.47
	Shallow Concentrated	520	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.06
21	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.090	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.29
	Shallow Concentrated	1450	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.18
22	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.36
	Shallow Concentrated	1600	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.17
23	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.56
	Shallow Concentrated	2500	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.46	0.28
24	Sheet	50	Resid. (1/2 ac)/Forest	0.25	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.14
	Shallow Concentrated	80	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.51	0.01
25	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.077	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.31
	Shallow Concentrated	1960	Unpaved	N/A	0.014	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.93	0.28
26	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.52
	Shallow Concentrated	660	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	0.08
27	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.43
	Shallow Concentrated	1500	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.50	0.28
28	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.063	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.33
	Shallow Concentrated	1960	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.46	0.37
29	Channel	2350	Some weeds, heavy brush	0.06	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	0.94	0.69
30	Sheet	100	Resid. (1/2 ac)/Forest	0.25	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.29
	Shallow Concentrated	150	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.03
31	Sheet	300	Resid. (1/2 ac)/Forest	0.25	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.56
	Shallow Concentrated	1450	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.47	0.27
34	Sheet	100	Resid. (1/2 ac)/Forest	0.3	0.005	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.38
	Shallow Concentrated	130	Unpaved	N/A	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00	0.04
35	Channel	990	Some weeds, heavy brush	0.06	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.55	0.50

Table O16. Calculated NRCS Method Variables and Peak Flow for Storm Events in College Branch Watershed for Residential (1/2-acre lots) Conditions

Watershed	Area (mi^2)	CN	S (in.)	2-Year Event					10-Year Event					25-Year Event					50-Year Event					100-Year Event				
				P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	0.016	73	3.75	4.1	0.18	1.6	363	9.0	6.2	0.12	3.2	385	19.5	7.1	0.11	4.0	390	24.5	8.0	0.09	4.8	392	29.4	8.9	0.08	5.6	392	34.4
2	0.050	73	3.75	4.1	0.18	1.6	267	21.0	6.2	0.12	3.2	283	45.4	7.1	0.11	4.0	286	56.7	8.0	0.09	4.8	287	68.1	8.9	0.08	5.6	287	79.6
3	0.019	73	3.75	4.1	0.18	1.6	293	8.6	6.2	0.12	3.2	311	18.7	7.1	0.11	4.0	315	23.4	8.0	0.09	4.8	316	28.1	8.9	0.08	5.6	316	32.9
4	0.016	73	3.75	4.1	0.18	1.6	338	8.6	6.2	0.12	3.2	359	18.6	7.1	0.11	4.0	364	23.3	8.0	0.09	4.8	365	28.0	8.9	0.08	5.6	365	32.7
5	0.035	78	2.82	4.1	0.14	2.0	588	40.5	6.2	0.09	3.8	600	78.9	7.1	0.08	4.6	600	96.0	8.0	0.07	5.4	600	113.3	8.9	0.06	6.2	600	130.9
6	0.007	78	2.82	4.1	0.14	2.0	436	6.0	6.2	0.09	3.8	452	11.9	7.1	0.08	4.6	452	14.5	8.0	0.07	5.4	452	17.1	8.9	0.06	6.2	452	19.8
7	0.032	78	2.82	4.1	0.14	2.0	343	21.6	6.2	0.09	3.8	360	43.2	7.1	0.08	4.6	360	52.6	8.0	0.07	5.4	360	62.1	8.9	0.06	6.2	360	71.7
8	0.016	78	2.82	4.1	0.14	2.0	405	12.8	6.2	0.09	3.8	420	25.4	7.1	0.08	4.6	420	30.9	8.0	0.07	5.4	420	36.5	8.9	0.06	6.2	420	42.1
9	0.020	78	2.82	4.1	0.14	2.0	367	14.1	6.2	0.09	3.8	380	27.9	7.1	0.08	4.6	380	33.9	8.0	0.07	5.4	380	40.0	8.9	0.06	6.2	380	46.2
10	0.018	78	2.82	4.1	0.14	2.0	639	22.9	6.2	0.09	3.8	650	44.5	7.1	0.08	4.6	650	54.1	8.0	0.07	5.4	650	63.9	8.9	0.06	6.2	650	73.9
11	0.019	78	2.82	4.1	0.14	2.0	413	15.4	6.2	0.09	3.8	428	30.4	7.1	0.08	4.6	428	37.0	8.0	0.07	5.4	428	43.6	8.9	0.06	6.2	428	50.4
12	0.052	78	2.82	4.1	0.14	2.0	378	38.4	6.2	0.09	3.8	392	76.0	7.1	0.08	4.6	392	92.3	8.0	0.07	5.4	392	109.0	8.9	0.06	6.2	392	126.0
13	0.051	76	3.11	4.1	0.15	1.8	337	31.5	6.2	0.10	3.6	354	64.5	7.1	0.09	4.4	355	79.1	8.0	0.08	5.2	355	93.8	8.9	0.07	6.0	355	108.7
14	0.021	78	2.82	4.1	0.14	2.0	352	14.2	6.2	0.09	3.8	365	28.2	7.1	0.08	4.6	365	34.3	8.0	0.07	5.4	365	40.4	8.9	0.06	6.2	365	46.7
15	0.034	78	2.82	4.1	0.14	2.0	386	25.9	6.2	0.09	3.8	400	51.2	7.1	0.08	4.6	400	62.3	8.0	0.07	5.4	400	73.6	8.9	0.06	6.2	400	85.0
16	0.014	76	3.25	4.1	0.16	1.8	399	10.1	6.2	0.10	3.5	419	21.0	7.1	0.09	4.3	420	25.7	8.0	0.08	5.1	420	30.6	8.9	0.07	5.9	420	35.5
17	0.027	73	3.75	4.1	0.18	1.6	324	13.9	6.2	0.12	3.2	344	30.2	7.1	0.11	4.0	349	37.9	8.0	0.09	4.8	350	45.5	8.9	0.08	5.6	350	53.1
18	0.014	78	2.82	4.1	0.14	2.0	429	11.9	6.2	0.09	3.8	444	23.6	7.1	0.08	4.6	444	28.7	8.0	0.07	5.4	444	33.9	8.9	0.06	6.2	444	39.2
20	0.009	78	2.82	4.1	0.14	2.0	394	6.7	6.2	0.09	3.8	408	13.2	7.1	0.08	4.6	408	16.1	8.0	0.07	5.4	408	19.0	8.9	0.06	6.2	408	21.9
21	0.023	78	2.82	4.1	0.14	2.0	421	18.8	6.2	0.09	3.8	436	37.1	7.1	0.08	4.6	436	45.1	8.0	0.07	5.4	436	53.2	8.9	0.06	6.2	436	61.5
22	0.014	78	2.82	4.1	0.14	2.0	394	11.2	6.2	0.09	3.8	408	22.1	7.1	0.08	4.6	408	26.9	8.0	0.07	5.4	408	31.7	8.9	0.06	6.2	408	36.6
23	0.037	78	2.82	4.1	0.14	2.0	311	22.4	6.2	0.09	3.8	322	44.3	7.1	0.08	4.6	322	53.9	8.0	0.07	5.4	322	63.6	8.9	0.06	6.2	322	73.5
24	0.001	78	2.82	4.1	0.14	2.0	588	1.6	6.2	0.09	3.8	600	3.2	7.1	0.08	4.6	600	3.9	8.0	0.07	5.4	600	4.6	8.9	0.06	6.2	600	5.3
25	0.024	73	3.75	4.1	0.18	1.6	356	13.4	6.2	0.12	3.2	377	29.0	7.1	0.11	4.0	383	36.4	8.0	0.09	4.8	384	43.6	8.9	0.08	5.6	384	51.0
26	0.015	78	2.82	4.1	0.14	2.0	367	10.8	6.2	0.09	3.8	380	21.4	7.1	0.08	4.6	380	26.0	8.0	0.07	5.4	380	30.7	8.9	0.06	6.2	380	35.5
27	0.017	78	2.82	4.1	0.14	2.0	343	11.8	6.2	0.09	3.8	355	23.3	7.1	0.08	4.6	355	28.3	8.0	0.07	5.4	355	33.4	8.9	0.06	6.2	355	38.6
28	0.029	78	2.82	4.1	0.14	2.0	343	19.9	6.2	0.09	3.8	355	39.3	7.1	0.08	4.6	355	47.8	8.0	0.07	5.4	355	56.4	8.9	0.06	6.2	355	65.2
29	0.083	84	1.98	4.1	0.10	2.4	358	71.8	6.2	0.06	4.3	358	128.6	7.1	0.06	5.2	358	153.8	8.0	0.05	6.0	358	179.3	8.9	0.04	6.9	358	205.0
30	0.002	76	3.25	4.1	0.16	1.8	475	1.5	6.2	0.10	3.5	495	3.0	7.1	0.09	4.3	496	3.7	8.0	0.08	5.1	496	4.4	8.9	0.07	5.9	496	5.1
31	0.020	81	2.38	4.1	0.12	2.2	318	14.1	6.2	0.08	4.0	322	26.3	7.1	0.07	4.9	322	31.8	8.0	0.06	5.7	322	37.2	8.9	0.05	6.6	322	42.8
34	0.001	84	1.98	4.1	0.10	2.4	580	2.1	6.2	0.06	4.3	580	3.7	7.1	0.06	5.2	580	4.5	8.0	0.05	6.0	580	5.2	8.9	0.04	6.9	580	6.0
35	0.030	76	3.25	4.1	0.16	1.8	399	21.2	6.2	0.10	3.5	419	43.9	7.1	0.09	4.3	420	53.9	8.0	0.08	5.1	420	64.0	8.9	0.07	5.9	420	74.3

Table O17. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for Residential (1/8 acre lots) Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
1	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.33
	Shallow Concentrated	825	Unpaved	N/A	0.030	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.81	0.08
2	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.54
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, light brush	0.05	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.91	0.09
3	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.46
	Shallow Concentrated	1515	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.31	0.18
4	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	915	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.72	0.09
5	Channel	1080	Some weeds, light brush	0.05	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.66	0.11
6	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.24
	Shallow Concentrated	600	Unpaved	N/A	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.95	0.06
7	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.35
	Shallow Concentrated	1420	Unpaved	N/A	0.025	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.57	0.15
8	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.26
	Shallow Concentrated	1080	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.60	0.12
9	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.043	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.26
	Shallow Concentrated	1725	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.27	0.21
10	Channel	660	Some weeds, light brush	0.05	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.57	0.07
11	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.057	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.23
	Shallow Concentrated	1180	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.14
12	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	1350	Unpaved	N/A	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.67	0.14
13	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.31
	Shallow Concentrated	1950	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.34	0.23
14	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.047	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.25
	Shallow Concentrated	600	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.13
	Channel	670	Some weeds, light brush	0.05	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.54	0.12
15	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.083	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.20
	Shallow Concentrated	1945	Unpaved	N/A	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.10	0.26
16	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.070	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.21
	Shallow Concentrated	1600	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.42	0.18
17	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	1560	Unpaved	N/A	0.028	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.68	0.16
18	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.097	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.18
	Shallow Concentrated	1135	Unpaved	N/A	0.015	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.97	0.16
20	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.027	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.31
	Shallow Concentrated	520	Unpaved	N/A	0.021	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.35	0.06
21	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.090	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19
	Shallow Concentrated	1450	Unpaved	N/A	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.18
22	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.050	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.24
	Shallow Concentrated	1600	Unpaved	N/A	0.026	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.58	0.17
23	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	2500	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.46	0.28
24	Sheet	50	Resid. (1/8) ac/Forest	0.15	0.016	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.09
	Shallow Concentrated	80	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.51	0.01
25	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.077	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.20
	Shallow Concentrated	1960	Unpaved	N/A	0.014	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.93	0.28
26	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.020	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.35
	Shallow Concentrated	660	Unpaved	N/A	0.023	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.43	0.08
27	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.033	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.28
	Shallow Concentrated	1500	Unpaved	N/A	0.009	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.50	0.28
28	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.063	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.22
	Shallow Concentrated	1960	Unpaved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.46	0.37
29	Channel	2350	Some weeds, light brush	0.05	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.26	0.52
30	Sheet	100	Resid. (1/8) ac/Forest	0.15	0.010	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.19
	Shallow Concentrated	150	Unpaved	N/A	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.32	0.03
31	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.017	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.37
	Shallow Concentrated	1450	Unpaved/Paved	N/A	0.008	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.47	0.27
34	Sheet	100	Resid. (1/8) ac/Forest	0.15	0.005	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.25
	Shallow Concentrated	130	Unpaved	N/A	0.004	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1.00	0.04
35	Channel	990	Some weeds, light brush	0.05	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.73	0.37

Table O18. Calculated NRCS Method Variables and Peak Flow for Storm Events in College Branch Watershed for Residential (1/8 acre lots) Conditions

Watershed	Area (mi^2)	CN	S (in.)	Time of Conc. (hr)	2-Year Event					10-Year Event					25-Year Event					50-Year Event					100-Year Event				
					P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)	P (in.)	Ia/P	Q (in.)	q_{um} (csm/in)	q_p (cfs)
1	0.016	79	2.66	0.41	4.1	0.13	2.0	444	14.3	6.2	0.09	3.9	456	27.6	7.1	0.07	4.7	456	33.5	8.0	0.07	5.5	456	39.4	8.9	0.06	6.4	456	45.5
2	0.050	79	2.66	0.73	4.1	0.13	2.0	338	34.3	6.2	0.09	3.9	348	66.7	7.1	0.07	4.7	348	80.8	8.0	0.07	5.5	348	95.2	8.9	0.06	6.4	348	109.7
3	0.019	79	2.66	0.64	4.1	0.13	2.0	360	13.7	6.2	0.09	3.9	370	26.6	7.1	0.07	4.7	370	32.2	8.0	0.07	5.5	370	37.9	8.9	0.06	6.4	370	43.7
4	0.016	79	2.66	0.47	4.1	0.13	2.0	420	13.8	6.2	0.09	3.9	432	26.8	7.1	0.07	4.7	432	32.4	8.0	0.07	5.5	432	38.2	8.9	0.06	6.4	432	44.0
5	0.035	83	2.05	0.11	4.1	0.10	2.4	640	53.2	6.2	0.07	4.3	640	95.9	7.1	0.06	5.1	640	114.8	8.0	0.05	6.0	640	134.0	8.9	0.05	6.8	640	153.3
6	0.007	83	2.05	0.30	4.1	0.10	2.4	505	8.4	6.2	0.07	4.3	505	15.2	7.1	0.06	5.1	505	18.2	8.0	0.05	6.0	505	21.2	8.9	0.05	6.8	505	24.3
7	0.032	83	2.05	0.50	4.1	0.10	2.4	420	31.9	6.2	0.07	4.3	420	57.4	7.1	0.06	5.1	420	68.8	8.0	0.05	6.0	420	80.3	8.9	0.05	6.8	420	91.9
8	0.016	83	2.05	0.37	4.1	0.10	2.4	474	18.1	6.2	0.07	4.3	474	32.7	7.1	0.06	5.1	474	39.1	8.0	0.05	6.0	474	45.6	8.9	0.05	6.8	474	52.2
9	0.020	83	2.05	0.47	4.1	0.10	2.4	432	20.0	6.2	0.07	4.3	432	36.1	7.1	0.06	5.1	432	43.2	8.0	0.05	6.0	432	50.4	8.9	0.05	6.8	432	57.7
10	0.018	83	2.05	0.07	4.1	0.10	2.4	650	28.1	6.2	0.07	4.3	650	50.7	7.1	0.06	5.1	650	60.7	8.0	0.05	6.0	650	70.9	8.9	0.05	6.8	650	81.1
11	0.019	83	2.05	0.37	4.1	0.10	2.4	474	21.3	6.2	0.07	4.3	474	38.3	7.1	0.06	5.1	474	45.9	8.0	0.05	6.0	474	53.6	8.9	0.05	6.8	474	61.3
12	0.052	83	2.05	0.42	4.1	0.10	2.4	452	55.3	6.2	0.07	4.3	452	99.8	7.1	0.06	5.1	452	119.5	8.0	0.05	6.0	452	139.4	8.9	0.05	6.8	452	159.5
13	0.051	82	2.24	0.54	4.1	0.11	2.3	401	46.2	6.2	0.07	4.1	404	85.1	7.1	0.06	5.0	404	102.3	8.0	0.06	5.8	404	119.7	8.9	0.05	6.7	404	137.3
14	0.021	83	2.05	0.49	4.1	0.10	2.4	424	20.7	6.2	0.07	4.3	424	37.3	7.1	0.06	5.1	424	44.6	8.0	0.05	6.0	424	52.1	8.9	0.05	6.8	424	59.6
15	0.034	83	2.05	0.45	4.1	0.10	2.4	440	35.6	6.2	0.07	4.3	440	64.2	7.1	0.06	5.1	440	76.9	8.0	0.05	6.0	440	89.7	8.9	0.05	6.8	440	102.7
16	0.014	81	2.35	0.39	4.1	0.11	2.2	458	14.4	6.2	0.08	4.1	465	27.0	7.1	0.07	4.9	465	32.5	8.0	0.06	5.7	465	38.1	8.9	0.05	6.6	465	43.8
17	0.027	79	2.66	0.54	4.1	0.13	2.0	393	21.8	6.2	0.09	3.9	404	42.4	7.1	0.07	4.7	404	51.4	8.0	0.07	5.5	404	60.5	8.9	0.06	6.4	404	69.7
18	0.014	83	2.05	0.34	4.1	0.10	2.4	487	16.4	6.2	0.07	4.3	487	29.5	7.1	0.06	5.1	487	35.3	8.0	0.05	6.0	487	41.2	8.9	0.05	6.8	487	47.2
20	0.009	83	2.05	0.37	4.1	0.10	2.4	474	9.7	6.2	0.07	4.3	474	17.5	7.1	0.06	5.1	474	21.0	8.0	0.05	6.0	474	24.5	8.9	0.05	6.8	474	28.0
21	0.023	83	2.05	0.37	4.1	0.10	2.4	474	25.5	6.2	0.07	4.3	474	45.9	7.1	0.06	5.1	474	55.0	8.0	0.05	6.0	474	64.2	8.9	0.05	6.8	474	73.4
22	0.014	83	2.05	0.41	4.1	0.10	2.4	456	15.6	6.2	0.07	4.3	456	28.1	7.1	0.06	5.1	456	33.7	8.0	0.05	6.0	456	39.3	8.9	0.05	6.8	456	45.0
23	0.037	83	2.05	0.66	4.1	0.10	2.4	365	31.8	6.2	0.07	4.3	365	57.2	7.1	0.06	5.1	365	68.5	8.0	0.05	6.0	365	80.0	8.9	0.05	6.8	365	91.5
24	0.001	83	2.05	0.11	4.1	0.10	2.4	640	2.1	6.2	0.07	4.3	640	3.9	7.1	0.06	5.1	640	4.6	8.0	0.05	6.0	640	5.4	8.9	0.05	6.8	640	6.2
25	0.024	79	2.66	0.49	4.1	0.13	2.0	412	20.0	6.2	0.09	3.9	424	38.9	7.1	0.07	4.7	424	47.1	8.0	0.07	5.5	424	55.5	8.9	0.06	6.4	424	64.0
26	0.015	83	2.05	0.42	4.1	0.10	2.4	452	16.1	6.2	0.07	4.3	452	29.0	7.1	0.06	5.1	452	34.7	8.0	0.05	6.0	452	40.5	8.9	0.05	6.8	452	46.3
27	0.017	83	2.05	0.56	4.1	0.10	2.4	396	16.4	6.2	0.07	4.3	396	29.6	7.1	0.06	5.1	396	35.4	8.0	0.05	6.0	396	41.3	8.9	0.05	6.8	396	47.3
28	0.029	83	2.05	0.59	4.1	0.10	2.4	384	26.9	6.2	0.07	4.3	384	48.4	7.1	0.06	5.1	384	58.0	8.0	0.05	6.0	384	67.7	8.9	0.05	6.8	384	77.4
29	0.083	87	1.56	0.52	4.1	0.08	2.7	412	91.7	6.2	0.05	4.7	412	159.1	7.1	0.04	5.5	412	188.6	8.0	0.04	6.4	412	218.4	8.9	0.04	7.3	412	248.4
30	0.002	81	2.35	0.22	4.1	0.11	2.2	536	2.0	6.2	0.08	4.1	541	3.8	7.1	0.07	4.9	541	4.6	8.0	0.06	5.7	541	5.4	8.9	0.05	6.6	541	6.1
31	0.020	85	1.76	0.65	4.1	0.09	2.5	368	19.0	6.2	0.06	4.5	368	33.5	7.1	0.05	5.3	368	39.8	8.0	0.04	6.2	368	46.3	8.9	0.04	7.1	368	52.8
34	0.001	87	1.56	0.29	4.1	0.08	2.7	510	2.0	6.2	0.05	4.7	510	3.5	7.1	0.04	5.5	510	4.2	8.0	0.04	6.4	510	4.9	8.9	0.04	7.3	510	5.5
35	0.030	81	2.35	0.37	4.1	0.11	2.2	468	30.8	6.2	0.08	4.1	474	57.6	7.1	0.07	4.9	474	69.4	8.0	0.06	5.7	474	81.3	8.9	0.05	6.6	474	93.4

Table O19. Calculated Time of Concentrationsfor Subwatersheds in College Branch Watershed for Residential (1/8 acre lot) Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
2	Sheet	300	Urban: Intensity 1/Forest	0.25	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.81
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Some weeds, heavy brush	0.06	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.18	0.12
5	Channel	1080	Some weeds, heavy brush	0.06	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	2.00	0.15
10	Channel	660	Some weeds, heavy brush	0.06	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	1.93	0.09
14	Channel	670	Some weeds, heavy brush	0.06	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.15	0.16
29	Channel	2350	Some weeds, heavy brush	0.06	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	0.94	0.69
35	Channel	990	Some weeds, heavy brush	0.06	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	0.55	0.50
TOTAL		7820													2.6

Table O20. Calculated Time of Concentrations for Subwatersheds in College Branch Watershed for Residential (1/8 acre lots) Conditions

Watershed	Type(s) of Flow	Flow Length (ft)	Land Use/Land Cover	Manning's n	Slope (ft/ft)	P_2 (in)	Diameter (ft)	Radius (ft)	Depth (ft)	Central Angle (Radians)	Channel Area (ft^2)	Wetted Perimeter (ft)	Hydraulic Radius (ft)	Velocity (ft/sec)	Time of Travel (hr)
2	Sheet	300	Resid. (1/8) ac/Forest	0.15	0.007	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.54
	Shallow Concentrated	800	Unpaved	N/A	0.02	4.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2.28	0.10
	Channel	970	Little or no brush	0.03	0.015	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	4.36	0.06
5	Channel	1080	Little or no brush	0.03	0.013	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	3.99	0.08
10	Channel	660	Little or no brush	0.03	0.012	4.1	N/A	N/A	N/A	N/A	6.55	11.03	0.59	3.86	0.05
14	Channel	670	Little or no brush	0.03	0.004	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	2.31	0.08
29	Channel	2350	Little or no brush	0.03	0.003	4.1	N/A	N/A	N/A	N/A	7.39	12.75	0.58	1.88	0.35
35	Channel	990	Little or no brush	0.03	0.002	4.1	N/A	N/A	N/A	N/A	1.83	5.27	0.35	1.10	0.25
TOTAL		7820													1.5

Table O21. Calculated Peak Flows for Entire Watershed of Concern for Residential (1/2 acre lots) Conditions

Length (ft)	7820				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	77				
S (in.)	2.92				
Time of Conc. (hr)	2.63				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	1.9	3.7	4.5	5.3	6.2
Ia/P	0.14	0.09	0.08	0.07	0.07
q_{um} (csm/in)	170	176	176	176	176
q_p (cfs)	250	498	606	717	829

Table O22. Calculated Peak Flows for Entire Watershed of Concern for Residential (1/8 acre lots) Conditions

Length (ft)	7820				
Area (Acres)	489.8				
Area (mi^2)	0.77				
CN	82				
S (in.)	2.14				
Time of Conc. (hr)	1.50				
	2-Year	10-Year	25-Year	50-Year	100-Year
P (in.)	4.1	6.2	7.1	8.0	8.9
Q (in.)	2.3	4.2	5.1	5.9	6.8
Ia/P	0.10	0.07	0.06	0.05	0.05
q_{um} (csm/in)	243	245	245	245	245
q_p (cfs)	432	790	948	1108	1269

APPENDIX P

HEC-RAS Profile and Cross-Sections for 2-Year Event

Two Stage Channel Design Cross-Sections

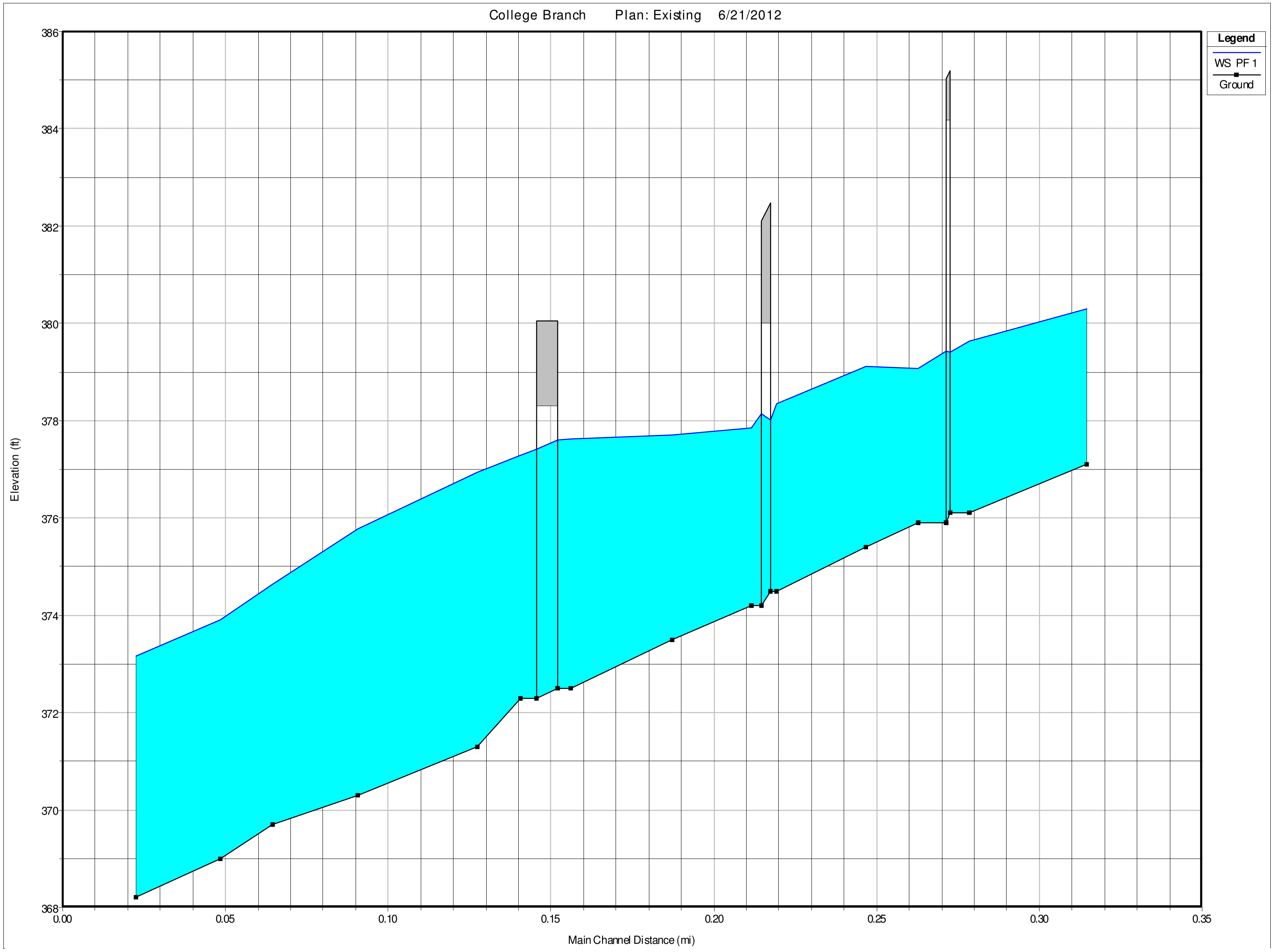

Figure P1. HEC-RAS 2-Year Event Profile Plot of Lower College Branch on the University of Arkansas Campus

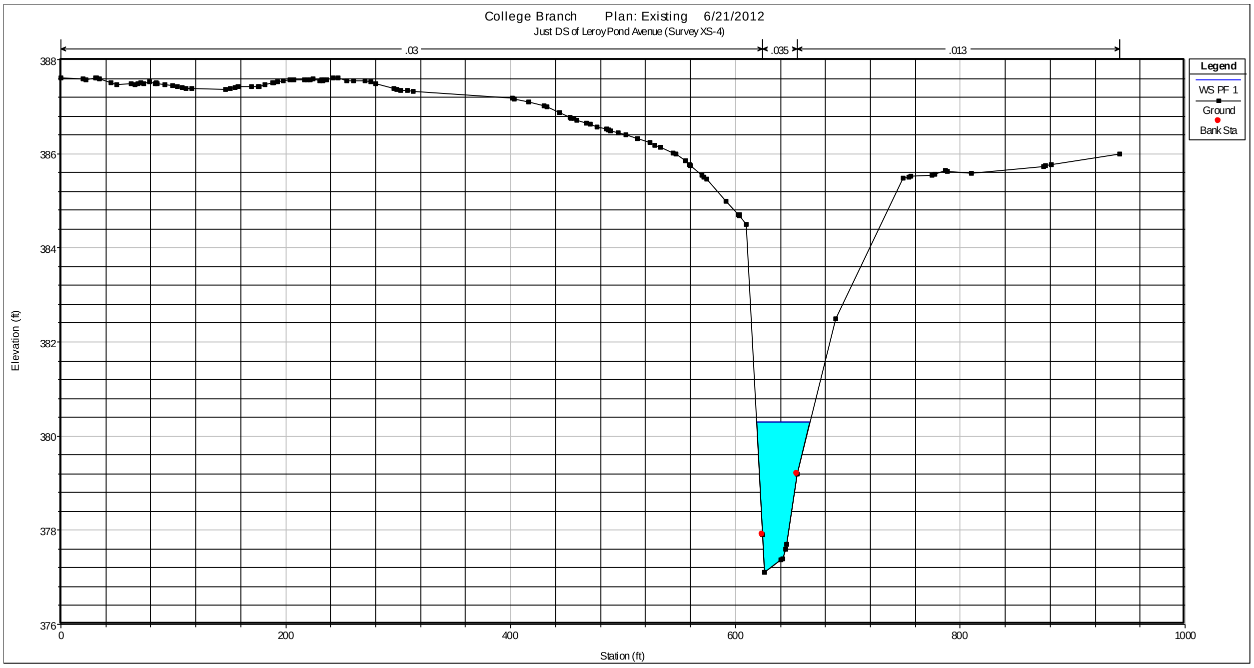

Figure P2. Cross-Section Plot for Survey XS-4 (Just downstream of Leroy Pond Drive)

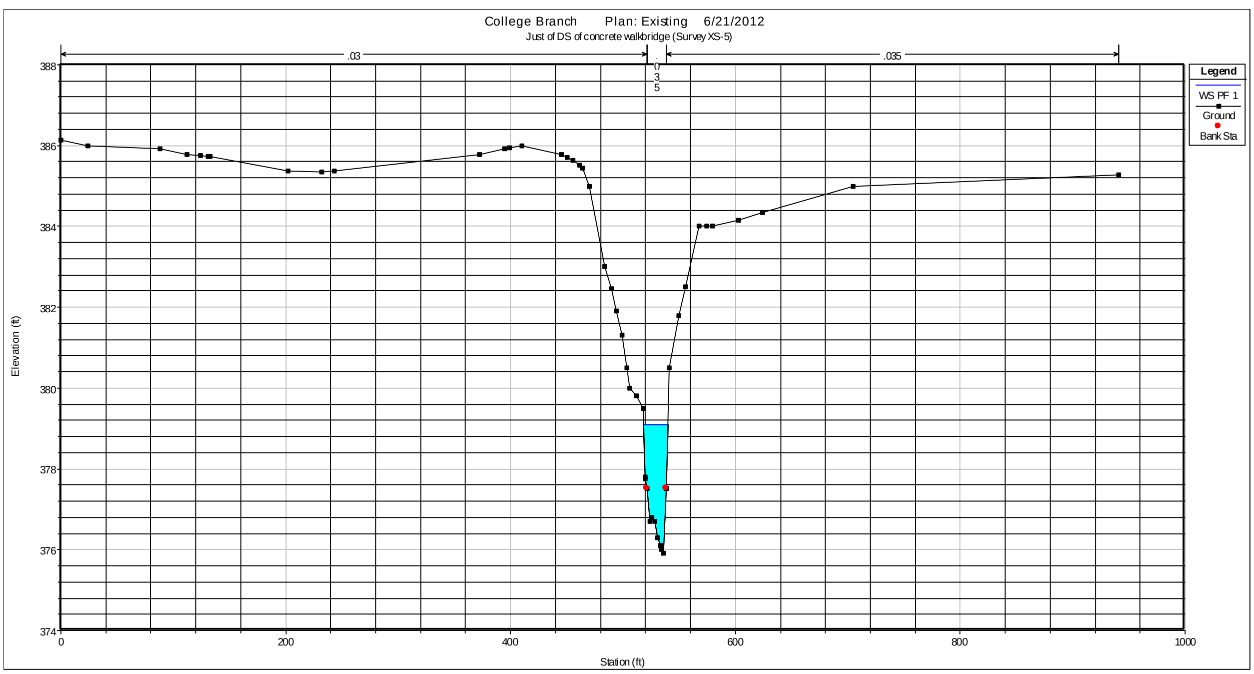

Figure P3. Cross-Section Plot for Survey XS-5 (Just downstream of walk bridge at Lot 56B)

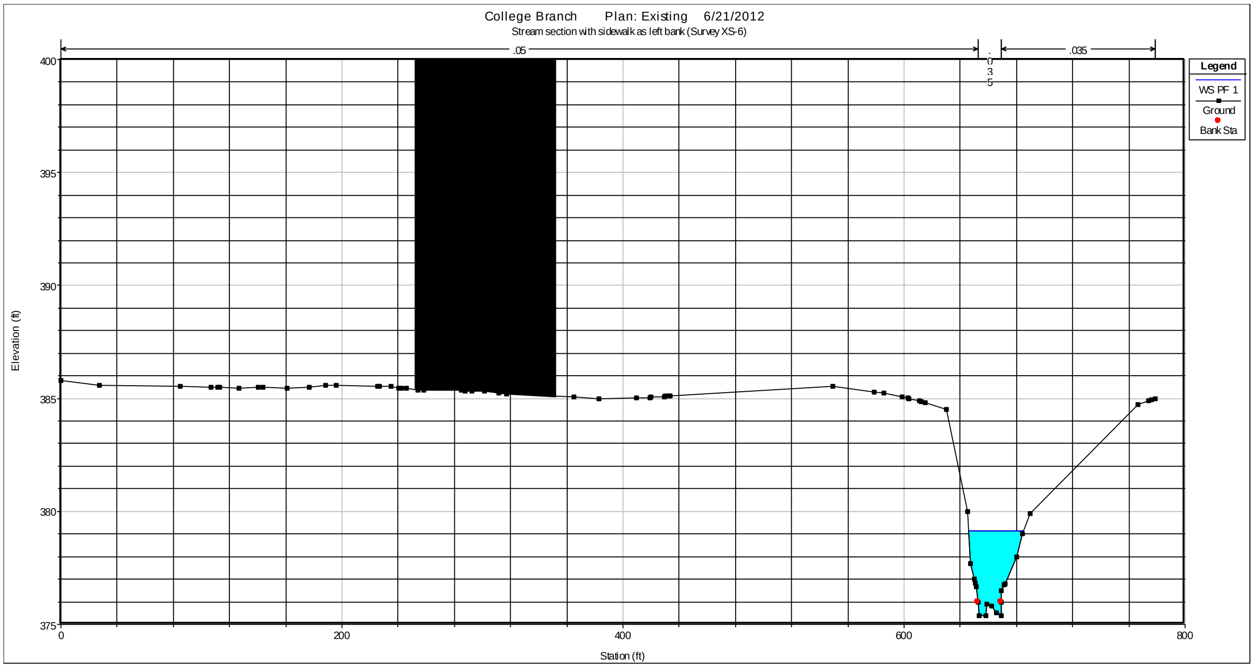

Figure P4. Cross-Section Plot of Survey XS-6 (Stream alongside sidewalk)

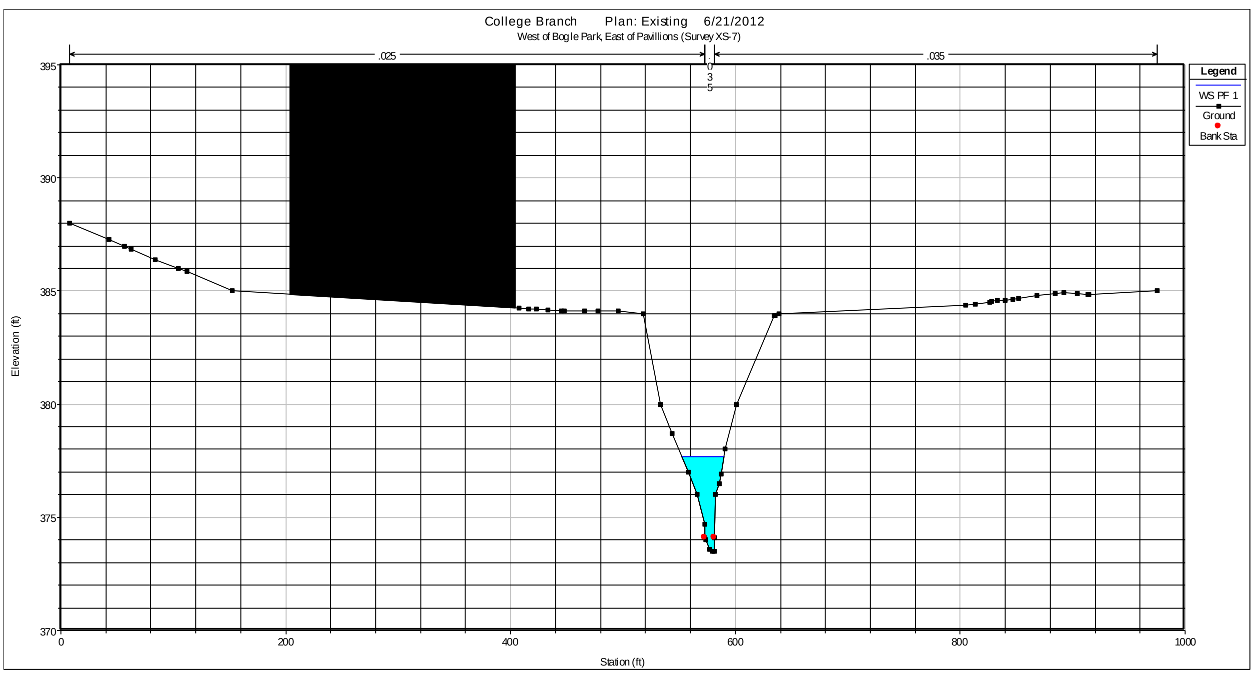

Figure P5. Cross-Section Plot of Survey XS-7 (Just upstream of Lady Razorback Road)

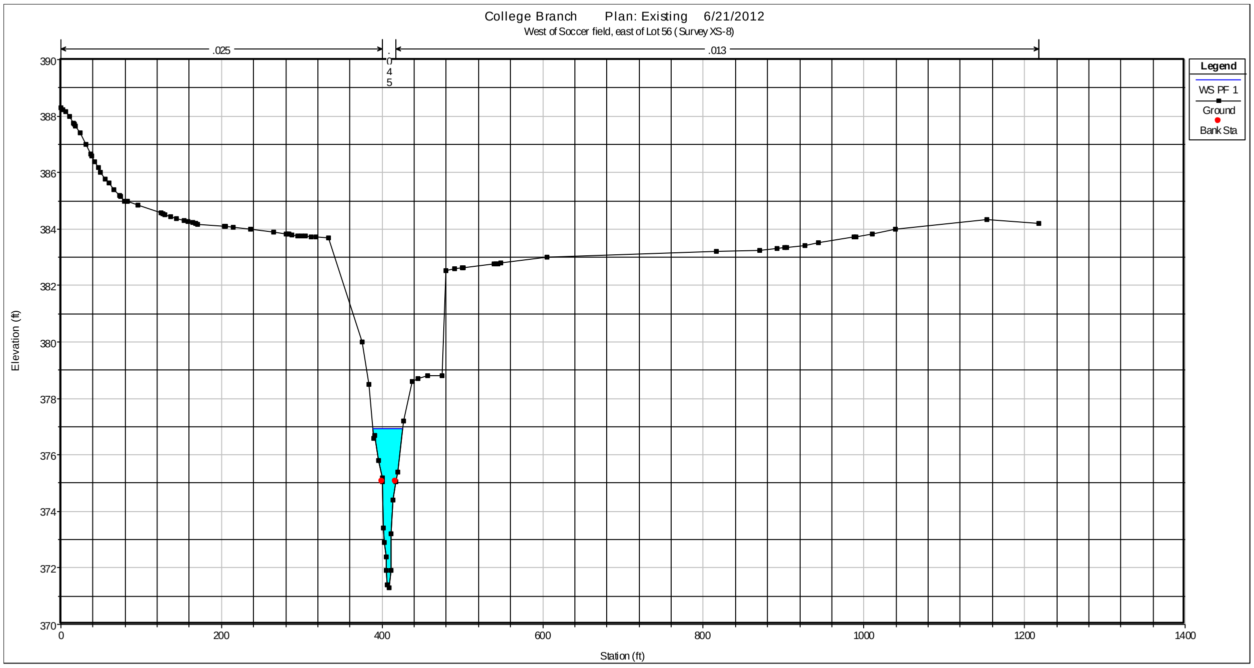

Figure P6. Cross-Section Plot of Survey XS-8 (Just downstream of Lady Razorback Road)

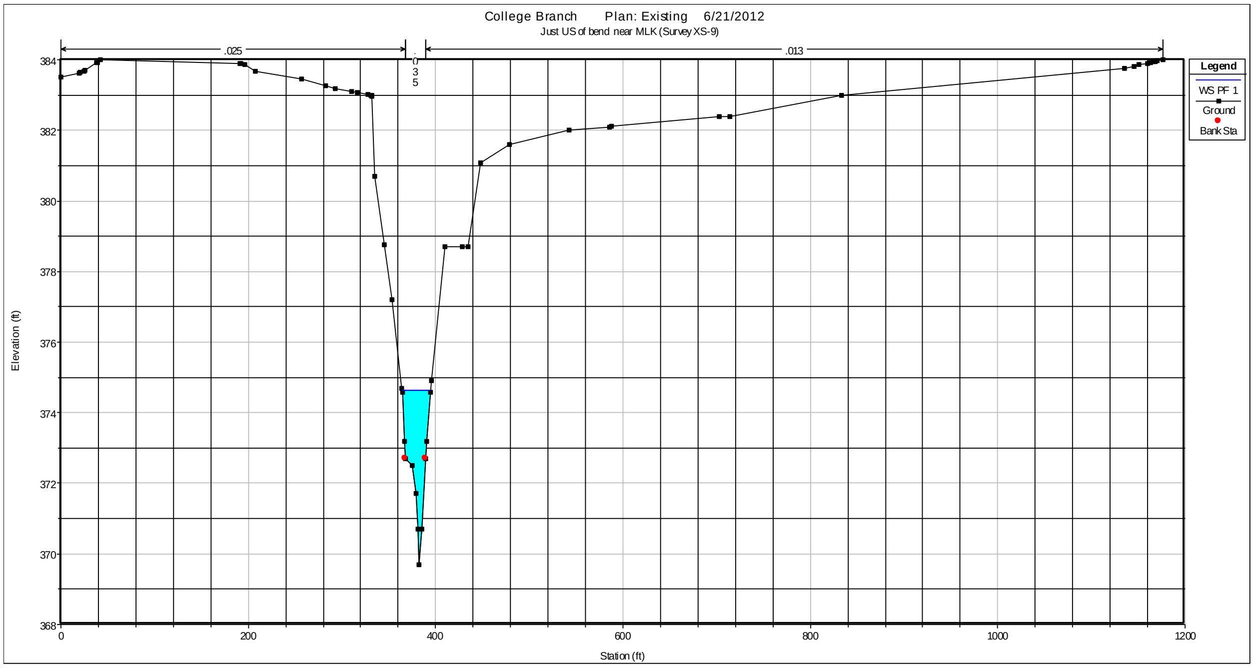

Figure P7. Cross-Section Plot of Survey XS-9 (Just upstream of large bend in College Branch)

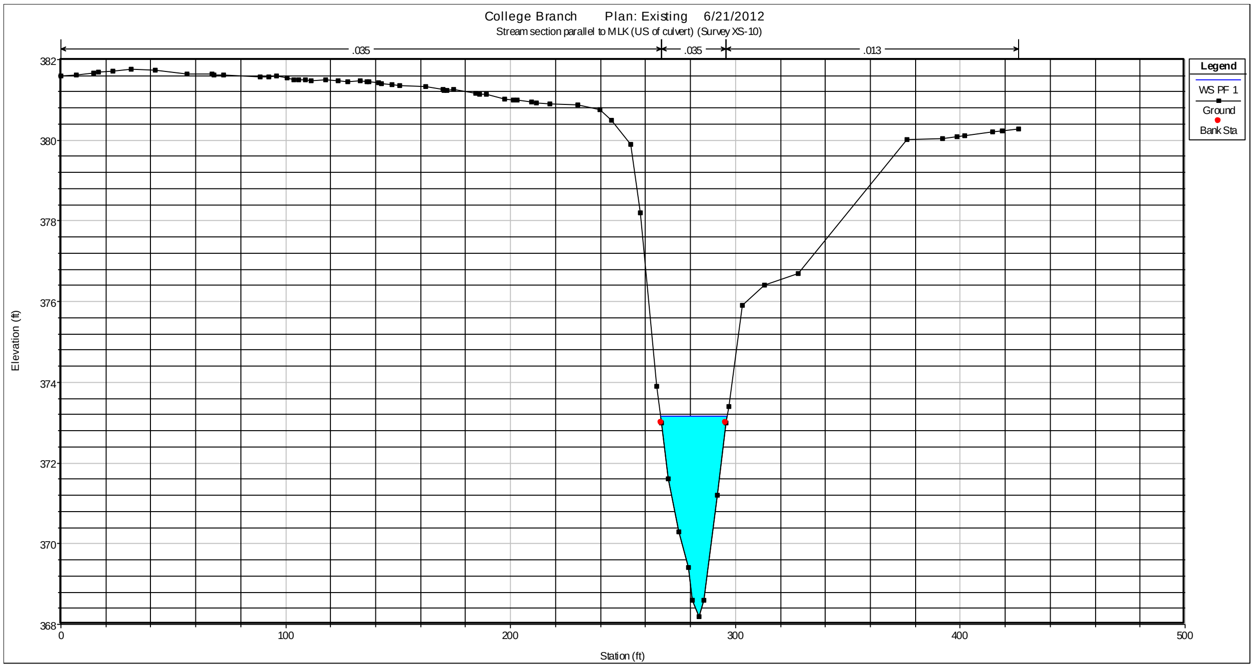

Figure P8. Cross-Section Plot of Survey XS-10 (Just upstream of U.S. Highway 62)

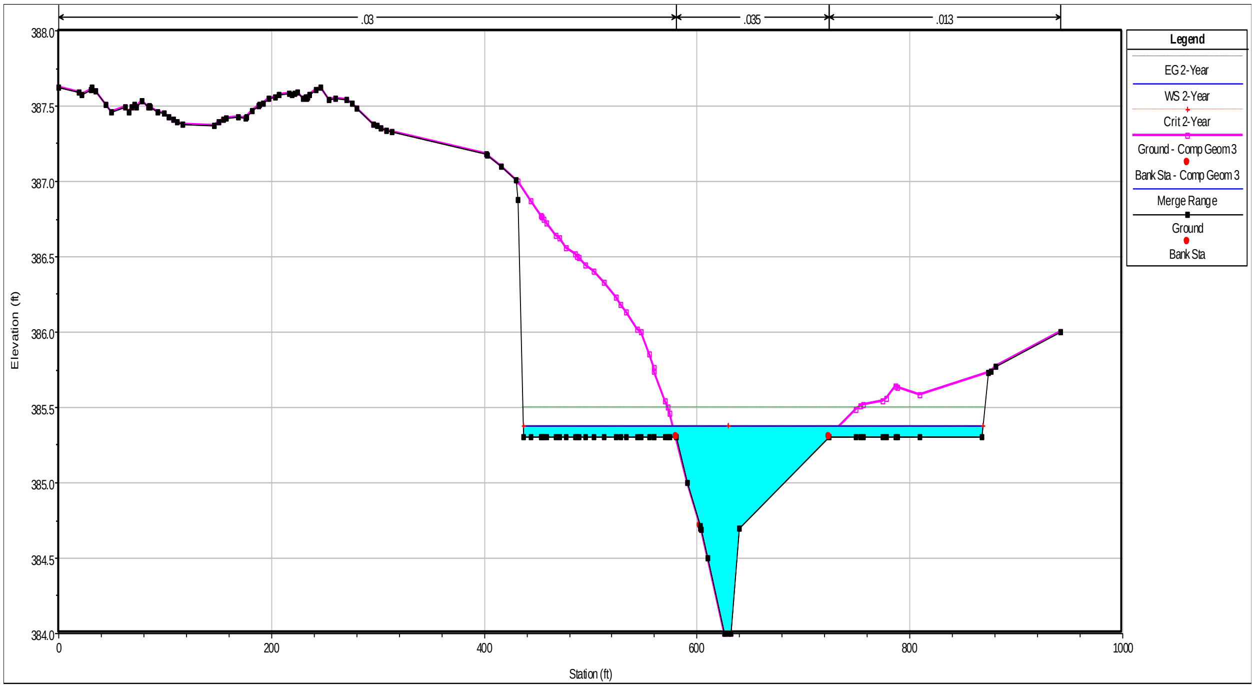

Figure P12. Two-Stage Channel Design for Cross-Section 4

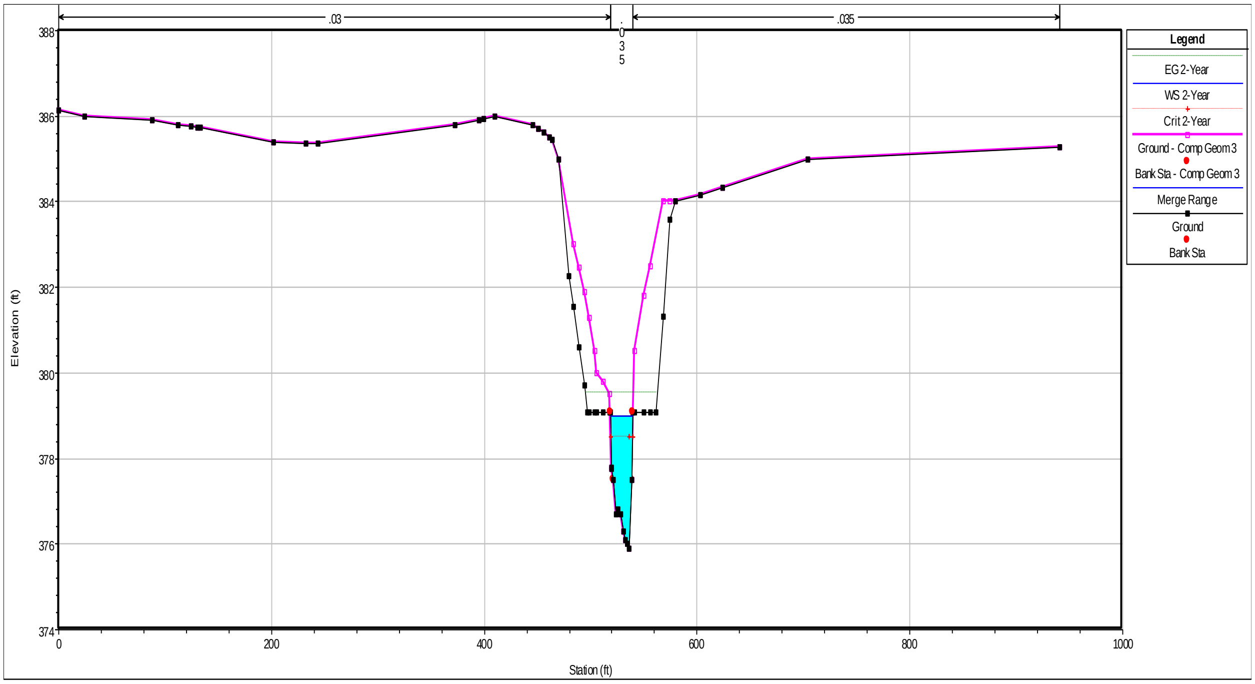

Figure P13. Two-Stage Channel Design for Cross-Section 5

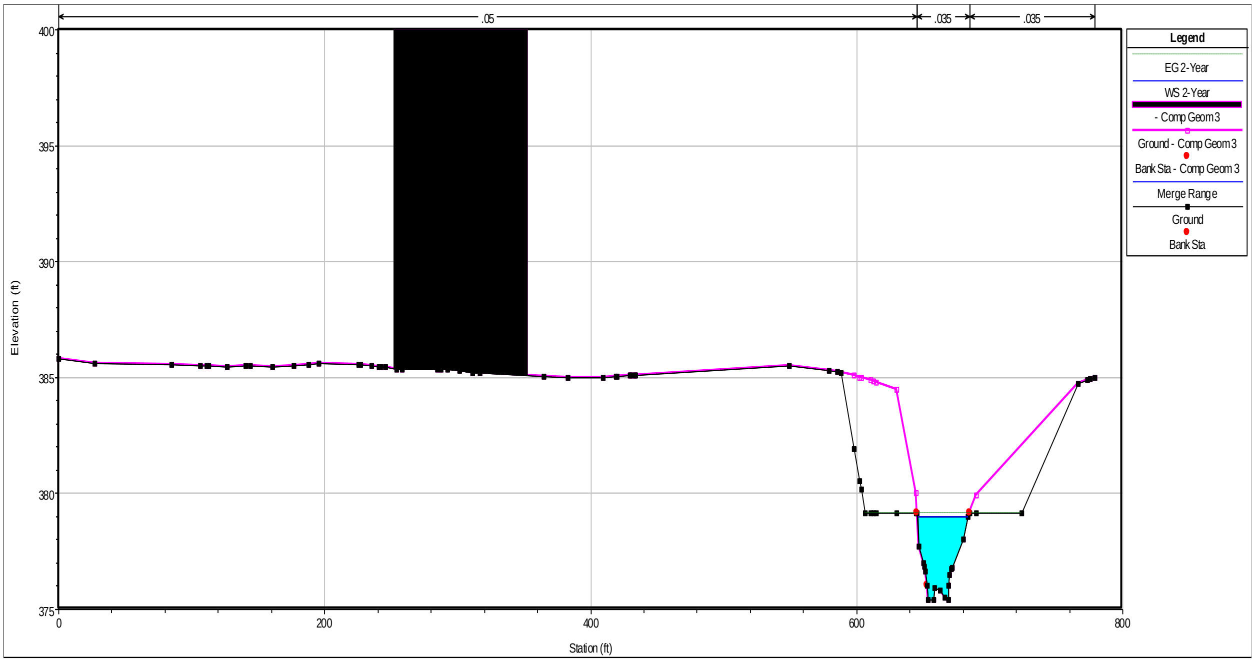

Figure P14. Two-Stage Channel Design for Cross-Section 6

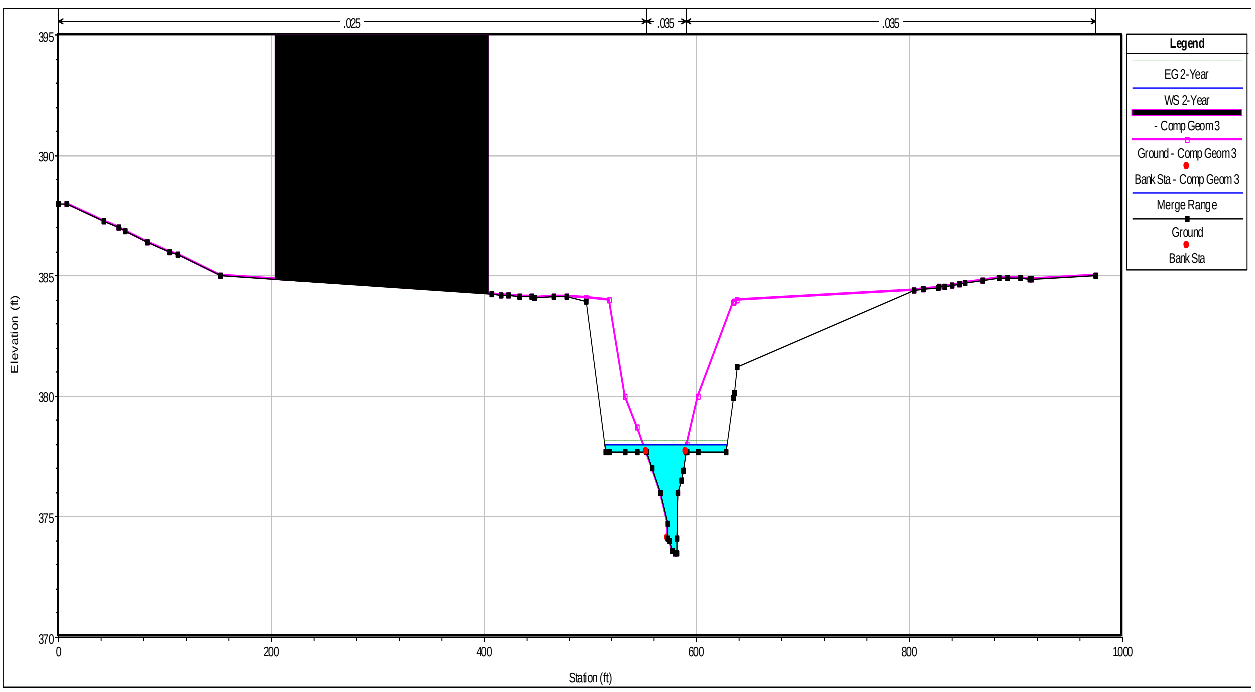

Figure P15. Two-Stage Channel Design for Cross-Section 7

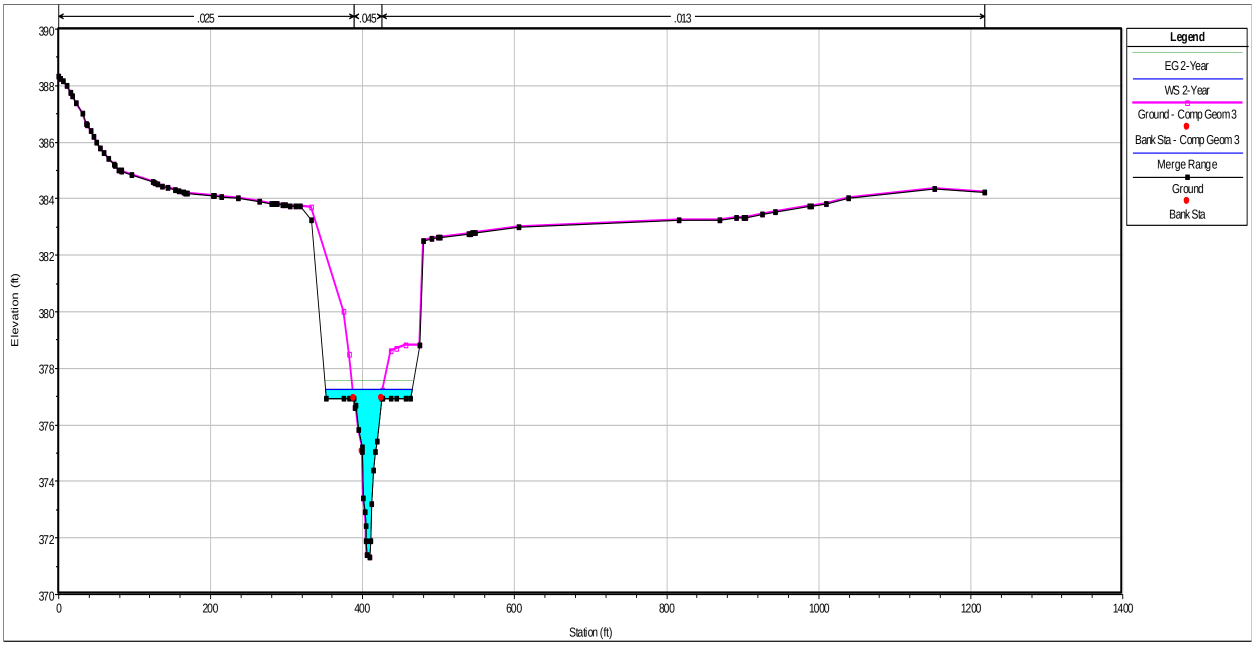

Figure P16. Two-Stage Channel Design for Cross-Section 8

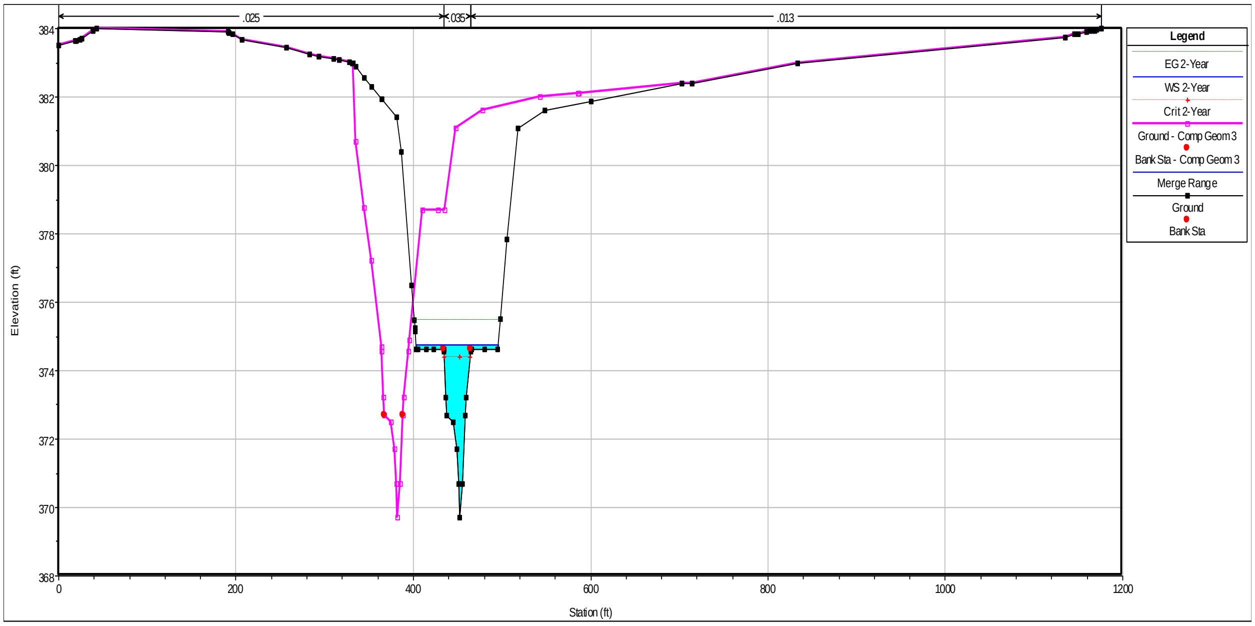

Figure P17. Original Two-Stage Channel Design for Cross-Section 9

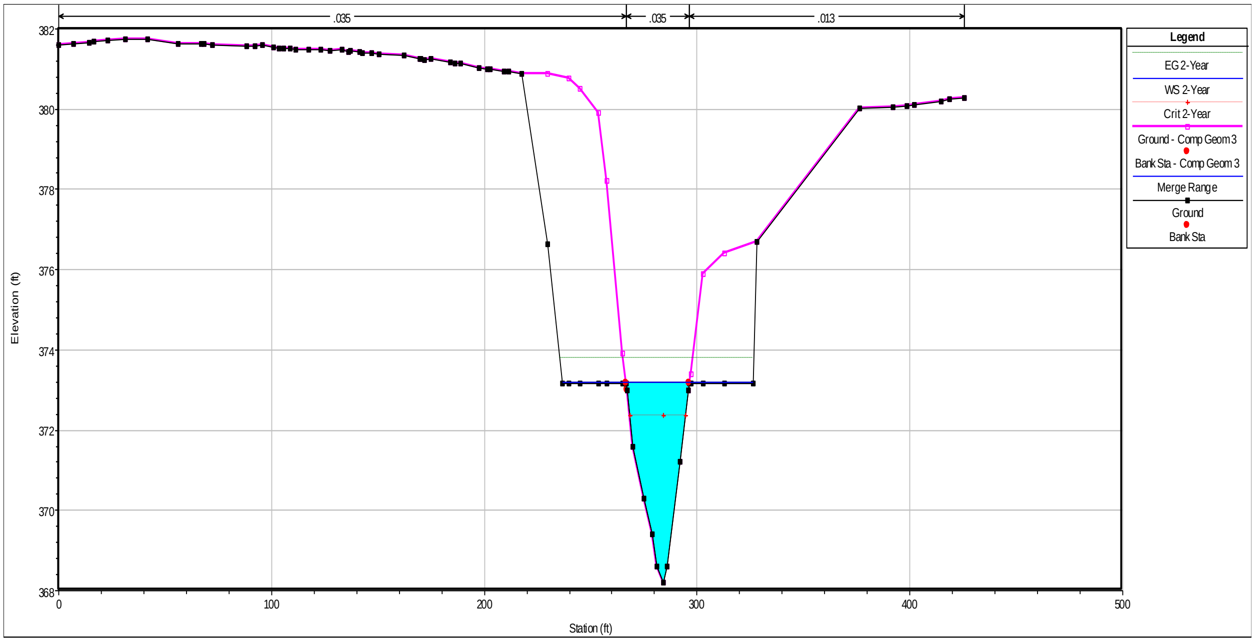

Figure P18. Updated Two-Stage Channel Design for Cross-Section 9

APPENDIX Q

Peak Flow for College Branch Watershed with Two-Stage Channel Cross-Sections

Table Q1. RAS Output for Existing Conditions for a 2-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	Exist	2 Yr	270	380.29	2.96	93.55	47.15	190.6	64.39	1.07
1470.7	Exist	2 Yr	270	379.62	5.01	55.37	22.04	83.8	16.73	0.28
1386.9	Exist	2 Yr	270	379.08	5.86	47.88	21.45	83.8	14.30	0.24
1303.1	Exist	2 Yr	270	379.13	3.52	94.54	39.08	145.4	41.31	0.69
1157.6	Exist	2 Yr	270	378.34	6.81	58.52	33.73	41.7	6.12	0.10
1116.0	Exist	2 Yr	270	377.84	7.48	51.98	31.44	127.7	17.08	0.28
988.27	Exist	2 Yr	270	377.7	4.8	71.12	37.77	164.6	34.29	0.57
823.67	Exist	2 Yr	270	377.62	3.13	111.3	49.47	80.6	25.76	0.43
743.03	Exist	2 Yr	521	377.29	8.04	65.37	30.12	71.1	8.84	0.15
671.94	Exist	2 Yr	521	376.93	5.89	86.88	37.01	192.9	32.74	0.55
479.09	Exist	2 Yr	521	375.77	6.69	81.01	35.7	139.8	20.89	0.35
339.31	Exist	2 Yr	521	374.63	7.54	69.28	30.59	83.3	11.05	0.18
256.02	Exist	2 Yr	521	373.91	7.59	68.87	30.5	137.2	18.07	0.30
118.86	Exist	2 Yr	521	373.16	6.28	82.99	29.78	118.9	18.93	0.32
								TOT	**330.5**	**5.51**

Table Q2. RAS Output for Two-Stage Channel Conditions for a 2-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	2 Stage	2 Yr	270	380.41	2.76	97.91	47.19	190.6	69.05	1.15
1470.7	2 Stage	2 Yr	270	379.67	4.79	56.31	22.04	83.8	17.49	0.29
1386.9	2 Stage	2 Yr	270	379.06	5.69	47.47	21.42	83.8	14.73	0.25
1303.1	2 Stage	2 Yr	270	379.08	2.91	92.66	38.69	145.4	49.97	0.83
1157.6	2 Stage	2 Yr	270	378.58	4.08	66.17	34.11	41.7	10.21	0.17
1116.0	2 Stage	2 Yr	270	378.45	3.74	72.2	36.01	127.7	34.16	0.57
988.27	2 Stage	2 Yr	270	378.18	3.02	89.53	41.45	164.6	54.50	0.91
823.67	2 Stage	2 Yr	270	378.04	2.06	131.2	52.51	80.6	39.15	0.65
743.03	2 Stage	2 Yr	521	377.78	6.37	81.74	35.39	71.1	11.16	0.19
671.94	2 Stage	2 Yr	521	376.76	6.46	80.68	35.62	192.9	29.85	0.50
479.09	2 Stage	2 Yr	521	375.51	5.39	96.61	34.12	139.8	25.93	0.43
339.31	2 Stage	2 Yr	521	374.44	6.76	77.06	29.52	83.3	12.32	0.21
256.02	2 Stage	2 Yr	521	373.24	8.27	62.99	26.73	137.2	16.58	0.28
118.86	2 Stage	2 Yr	521	372.38	6.42	81.17	26.81	118.9	18.51	0.31
								TOT	**403.64**	**6.73**

Table Q3. RAS Output for Existing Conditions for a 10-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	Exist	10Yr	586	381.84	3.17	181.48	66.39	190.6	60.12	1.00
1470.7	Exist	10Yr	586	381.18	6.16	108.55	43.57	83.8	13.60	0.23
1386.9	Exist	10Yr	586	380.6	7.29	92.7	38.74	83.8	11.49	0.19
1303.1	Exist	10Yr	586	380.74	4.67	171.47	60.85	145.4	31.14	0.52
1157.6	Exist	10Yr	586	380.22	6.96	143.42	57.53	41.7	5.99	0.10
1116.0	Exist	10Yr	586	379.62	7.75	126.86	53.52	127.7	16.48	0.27
988.27	Exist	10Yr	586	379.63	4.56	168.02	63.03	164.6	36.10	0.60
823.67	Exist	10Yr	586	379.59	3.17	232.7	68.5	80.6	25.44	0.42
743.03	Exist	10Yr	1130	378.86	8.41	125.32	46.33	71.1	8.45	0.14
671.94	Exist	10Yr	1130	378.22	7.22	142.87	50.27	192.9	26.71	0.45
479.09	Exist	10Yr	1130	377.44	7.36	153.87	52.58	139.8	18.99	0.32
339.31	Exist	10Yr	1130	375.98	9.45	118.17	41.61	83.3	8.81	0.15
256.02	Exist	10Yr	1130	375.4	9.05	123.06	42.55	137.2	15.16	0.25
118.86	Exist	10Yr	1130	374.76	8.45	136.31	36.77	118.9	14.07	0.23
								TOT	**292.56**	**4.88**

Table Q4. RAS Output for Two-Stage Channel Conditions for a 10-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	2 Stage	10Yr	586	381.3	2.85	221.26	152.54	190.6	66.87	1.11
1470.7	2 Stage	10Yr	586	380.71	4.87	127.99	74.24	83.8	17.21	0.29
1386.9	2 Stage	10Yr	586	380.07	6.39	114.53	70.57	83.8	13.11	0.22
1303.1	2 Stage	10Yr	586	380.09	3.63	211.85	127.4	145.4	40.06	0.67
1157.6	2 Stage	10Yr	586	379.8	3.97	195.91	111.85	41.7	10.50	0.17
1116.0	2 Stage	10Yr	586	379.4	4.4	173.74	113.22	127.7	29.03	0.48
988.27	2 Stage	10Yr	586	379.25	3.14	224.83	130.39	164.6	52.42	0.87
823.67	2 Stage	10Yr	586	379.16	2.32	306.92	167.57	80.6	34.76	0.58
743.03	2 Stage	10Yr	1130	378.5	7.02	160.76	117.65	71.1	10.13	0.17
671.94	2 Stage	10Yr	1130	377.69	6.34	174.42	118.29	192.9	30.42	0.51
479.09	2 Stage	10Yr	1130	376.41	6.99	181.64	127.95	139.8	20.00	0.33
339.31	2 Stage	10Yr	1130	375.45	7.56	161.89	101.02	83.3	11.02	0.18
256.02	2 Stage	10Yr	1130	375.36	5.11	221.61	101.01	137.2	26.84	0.45
118.86	2 Stage	10Yr	1130	374.18	8.42	135.9	34.36	118.9	14.12	0.24
								TOT	**376.5**	**6.27**

Table Q5. RAS Output for Existing Conditions for a 25-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	Exist	25Yr	777	382.68	3.09	241.35	78.54	190.6	61.68	1.03
1470.7	Exist	25Yr	777	382.21	5.66	160.86	58.8	83.8	14.81	0.25
1386.9	Exist	25Yr	777	381.97	6.14	157.99	57.97	83.8	13.65	0.23
1303.1	Exist	25Yr	777	382.05	4.29	267.51	86.01	145.4	33.90	0.56
1157.6	Exist	25Yr	777	381.85	5.37	251.82	72.28	41.7	7.76	0.13
1116.0	Exist	25Yr	777	380.88	6.67	204.68	68.91	127.7	19.15	0.32
988.27	Exist	25Yr	777	380.89	3.89	257.84	79.01	164.6	42.31	0.71
823.67	Exist	25Yr	777	380.87	2.87	320.7	69.58	80.6	28.10	0.47
743.03	Exist	25Yr	1500	379.91	8.17	186.07	95.6	71.1	8.70	0.15
671.94	Exist	25Yr	1500	378.93	8.03	188.1	94.49	192.9	24.02	0.40
479.09	Exist	25Yr	1500	378.51	6.51	253.02	123.4	139.8	21.47	0.36
339.31	Exist	25Yr	1500	376.74	9.6	152.29	47.79	83.3	8.68	0.14
256.02	Exist	25Yr	1500	376.11	9.41	155.27	48.29	137.2	14.58	0.24
118.86	Exist	25Yr	1500	375.49	9.35	164.13	39.78	118.9	12.71	0.21
								TOT	**311.5**	**5.19**

Table Q6. RAS Output for Two-Stage Channel Conditions for a 25-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	2 Stage	25Yr	777	381.69	2.81	282.11	156.35	190.6	67.83	1.13
1470.7	2 Stage	25Yr	777	381.06	5.15	154.33	76.98	83.8	16.27	0.27
1386.9	2 Stage	25Yr	777	380.76	5.84	164.85	74.92	83.8	14.35	0.24
1303.1	2 Stage	25Yr	777	380.8	3.44	304.86	134.93	145.4	42.27	0.70
1157.6	2 Stage	25Yr	777	380.62	3.56	290.22	118.07	41.7	11.71	0.20
1116.0	2 Stage	25Yr	777	379.98	4.26	240.21	115.77	127.7	29.99	0.50
988.27	2 Stage	25Yr	777	379.89	2.94	308.88	133.66	164.6	55.99	0.93
823.67	2 Stage	25Yr	777	379.83	2.2	421.19	172.72	80.6	36.65	0.61
743.03	2 Stage	25Yr	1500	378.8	7.11	196.92	122.38	71.1	10.00	0.17
671.94	2 Stage	25Yr	1500	377.92	6.9	201.95	120.49	192.9	27.95	0.47
479.09	2 Stage	25Yr	1500	376.73	7.43	223.12	138.04	139.8	18.81	0.31
339.31	2 Stage	25Yr	1500	376.31	5.85	252.46	110.68	83.3	14.24	0.24
256.02	2 Stage	25Yr	1500	376.28	4.34	317.75	107.08	137.2	31.60	0.53
118.86	2 Stage	25Yr	1500	374.96	9.34	163.78	37.58	118.9	12.73	0.21
								TOT	**390.38**	**6.51**

Table Q7. RAS Output for Existing Conditions for a 50-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	Exist	50Yr	932	384.46	2.09	416.87	118.5	190.6	91.19	1.52
1470.7	Exist	50Yr	932	384.34	3.47	325.15	106.3	83.8	24.15	0.40
1386.9	Exist	50Yr	932	384.16	4.05	328.89	126.7	83.8	20.69	0.34
1303.1	Exist	50Yr	932	384.19	2.97	496.31	127.3	145.4	48.96	0.82
1157.6	Exist	50Yr	932	384.07	4.32	429.65	163.8	41.7	9.65	0.16
1116.0	Exist	50Yr	932	381.51	6.52	249.07	72.07	127.7	19.59	0.33
988.27	Exist	50Yr	932	381.51	3.87	309.37	86.69	164.6	42.53	0.71
823.67	Exist	50Yr	932	381.49	2.97	363.96	70.11	80.6	27.15	0.45
743.03	Exist	50Yr	1798	380.14	8.45	208.27	99.69	71.1	8.41	0.14
671.94	Exist	50Yr	1798	379.21	8.04	214	96.31	192.9	23.99	0.40
479.09	Exist	50Yr	1798	379.15	5.49	340.03	148.2	139.8	25.46	0.42
339.31	Exist	50Yr	1798	377.25	9.8	177.31	51.88	83.3	8.50	0.14
256.02	Exist	50Yr	1798	376.64	9.52	182.32	52.72	137.2	14.41	0.24
118.86	Exist	50Yr	1798	376.03	9.98	186.26	44.24	118.9	11.91	0.20
								TOT	**376.6**	**6.28**

Table Q8. RAS Output for Two-Stage Channel Conditions for a 50-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	2 Stage	50Yr	932	382.13	2.56	352	160.61	190.6	74.45	1.24
1470.7	2 Stage	50Yr	932	381.63	4.5	199.84	81.5	83.8	18.62	0.31
1386.9	2 Stage	50Yr	932	381.54	5.05	225	79.81	83.8	16.59	0.28
1303.1	2 Stage	50Yr	932	381.58	3.06	413.96	143.25	145.4	47.52	0.79
1157.6	2 Stage	50Yr	932	381.47	3.13	393.29	124.52	41.7	13.31	0.22
1116.0	2 Stage	50Yr	932	380.55	3.99	306.78	118.27	127.7	32.02	0.53
988.27	2 Stage	50Yr	932	380.49	2.72	390.33	136.76	164.6	60.52	1.01
823.67	2 Stage	50Yr	932	380.45	2.05	530.7	177.51	80.6	39.34	0.66
743.03	2 Stage	50Yr	1798	379.1	6.74	234.67	127.13	71.1	10.55	0.18
671.94	2 Stage	50Yr	1798	378.13	7.06	226.5	122.41	192.9	27.32	0.46
479.09	2 Stage	50Yr	1798	377.26	6.3	301.65	155.35	139.8	22.19	0.37
339.31	2 Stage	50Yr	1798	376.99	5.04	330.55	118.37	83.3	16.53	0.28
256.02	2 Stage	50Yr	1798	376.97	4.03	392.55	111.68	137.2	34.03	0.57
118.86	2 Stage	50Yr	1798	375.5	9.97	184.68	39.82	118.9	11.92	0.20
								TOT	**424.9**	**7.08**

Table Q9. RAS Output for Existing Conditions for a 100-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	Exist	100Yr	1097	384.8	2.25	460.95	136.56	190.6	84.71	1.41
1470.7	Exist	100Yr	1097	384.7	3.7	363.96	124.3	83.8	22.65	0.38
1386.9	Exist	100Yr	1097	384.4	4.44	368.17	161.49	83.8	18.87	0.31
1303.1	Exist	100Yr	1097	384.5	3.28	532.52	132.64	145.4	44.34	0.74
1157.6	Exist	100Yr	1097	384.3	4.82	473.5	181.39	41.7	8.65	0.14
1116.0	Exist	100Yr	1097	381.8	6.97	272.69	73.7	127.7	18.33	0.31
988.27	Exist	100Yr	1097	381.8	4.16	338.11	90.68	164.6	39.57	0.66
823.67	Exist	100Yr	1097	381.8	3.26	386.21	70.38	80.6	24.74	0.41
743.03	Exist	100Yr	2117	380.4	8.57	232.62	103.98	71.1	8.29	0.14
671.94	Exist	100Yr	2117	379.6	7.62	248.55	98.67	192.9	25.31	0.42
479.09	Exist	100Yr	2117	379.8	4.74	438.11	170.51	139.8	29.49	0.49
339.31	Exist	100Yr	2117	377.7	10	203.36	56.13	83.3	8.33	0.14
256.02	Exist	100Yr	2117	377.2	9.63	210.6	57.26	137.2	14.24	0.24
118.86	Exist	100Yr	2117	376.6	10.59	213.09	60.43	118.9	11.22	0.19
								TOTAL	**358.73**	**5.98**

Table Q10. RAS Output for Two-Stage Channel Conditions for a 100-Year Event

River Station	Plan	Prof.	Q Tot	W.S. Elev	Chan. Vel.	Flow Area	Top Width	Length to next XS	Tt	Tt
			cfs	(ft)	(ft/s)	(sq ft)	(ft)	(ft)	(s)	min
1661.3	2 Stage	100Yr	1097	383.0	2	491.13	168.78	190.6	95.29	1.59
1470.7	2 Stage	100Yr	1097	382.7	3.38	289.67	89.77	83.8	24.79	0.41
1386.9	2 Stage	100Yr	1097	382.7	4.14	318.45	86.87	83.8	20.24	0.34
1303.1	2 Stage	100Yr	1097	382.7	2.57	581.3	155.79	145.4	56.59	0.94
1157.6	2 Stage	100Yr	1097	382.6	2.66	543.54	133.36	41.7	15.67	0.26
1116.0	2 Stage	100Yr	1097	381.4	3.46	411.66	122.1	127.7	36.92	0.62
988.27	2 Stage	100Yr	1097	381.4	2.35	515.74	141.39	164.6	70.04	1.17
823.67	2 Stage	100Yr	1097	381.4	1.78	697.76	184.58	80.6	45.30	0.76
743.03	2 Stage	100Yr	2117	379.4	6.57	270.61	131.49	71.1	10.82	0.18
671.94	2 Stage	100Yr	2117	378.5	6.64	266.93	125.52	192.9	29.04	0.48
479.09	2 Stage	100Yr	2117	378.0	5.15	409.21	173.45	139.8	27.14	0.45
339.31	2 Stage	100Yr	2117	377.7	4.5	416.13	126.26	83.3	18.51	0.31
256.02	2 Stage	100Yr	2117	377.7	3.82	471.39	116.37	137.2	35.90	0.60
118.86	2 Stage	100Yr	2117	376.0	10.57	207.31	44.62	118.9	11.25	0.19
								TOTAL	**497.51**	**8.29**

APPENDIX R

Flow Direction Map

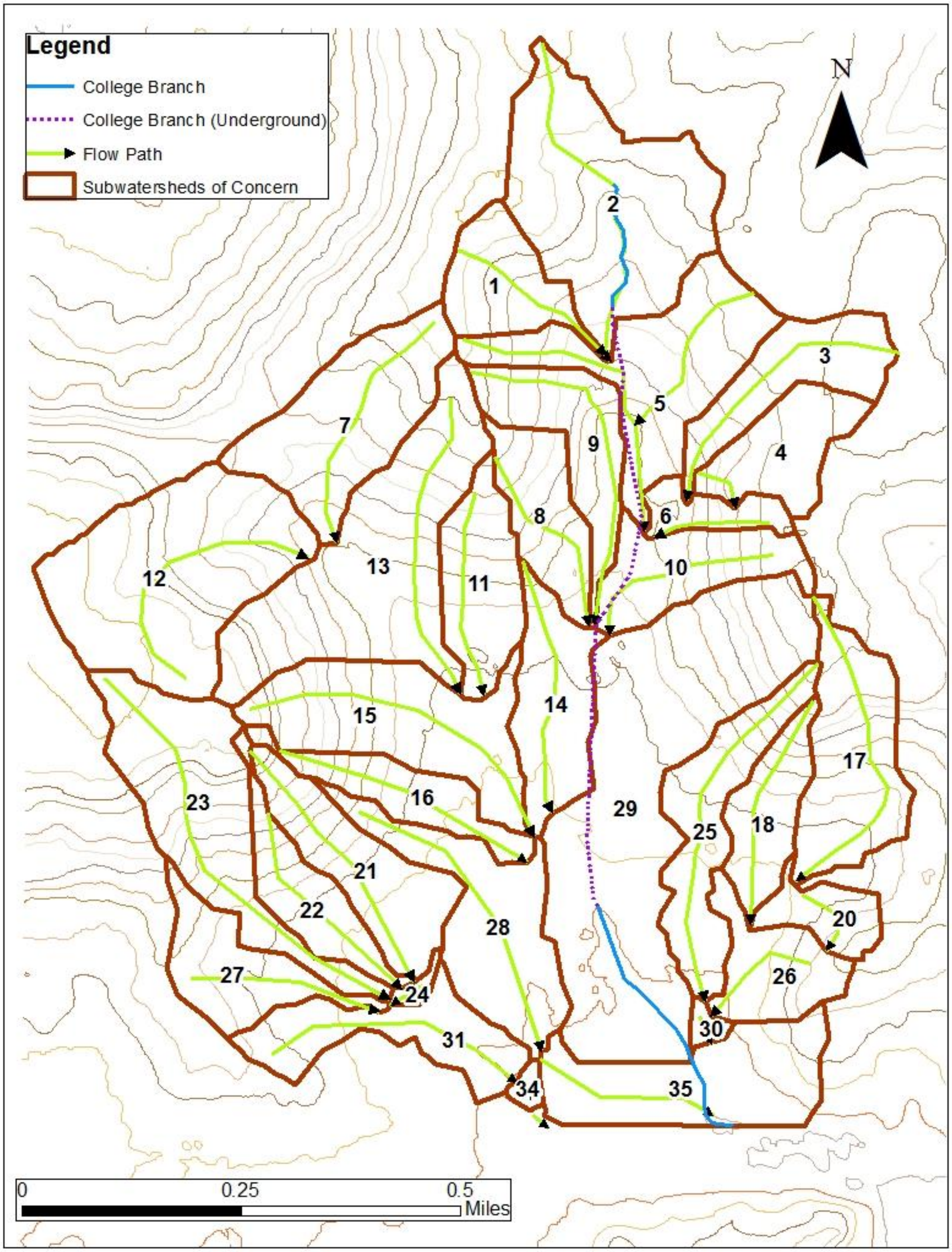

Figure R1. Flow Direction Map

APPENDIX S

Flood Boundary Maps for 100-Year Event

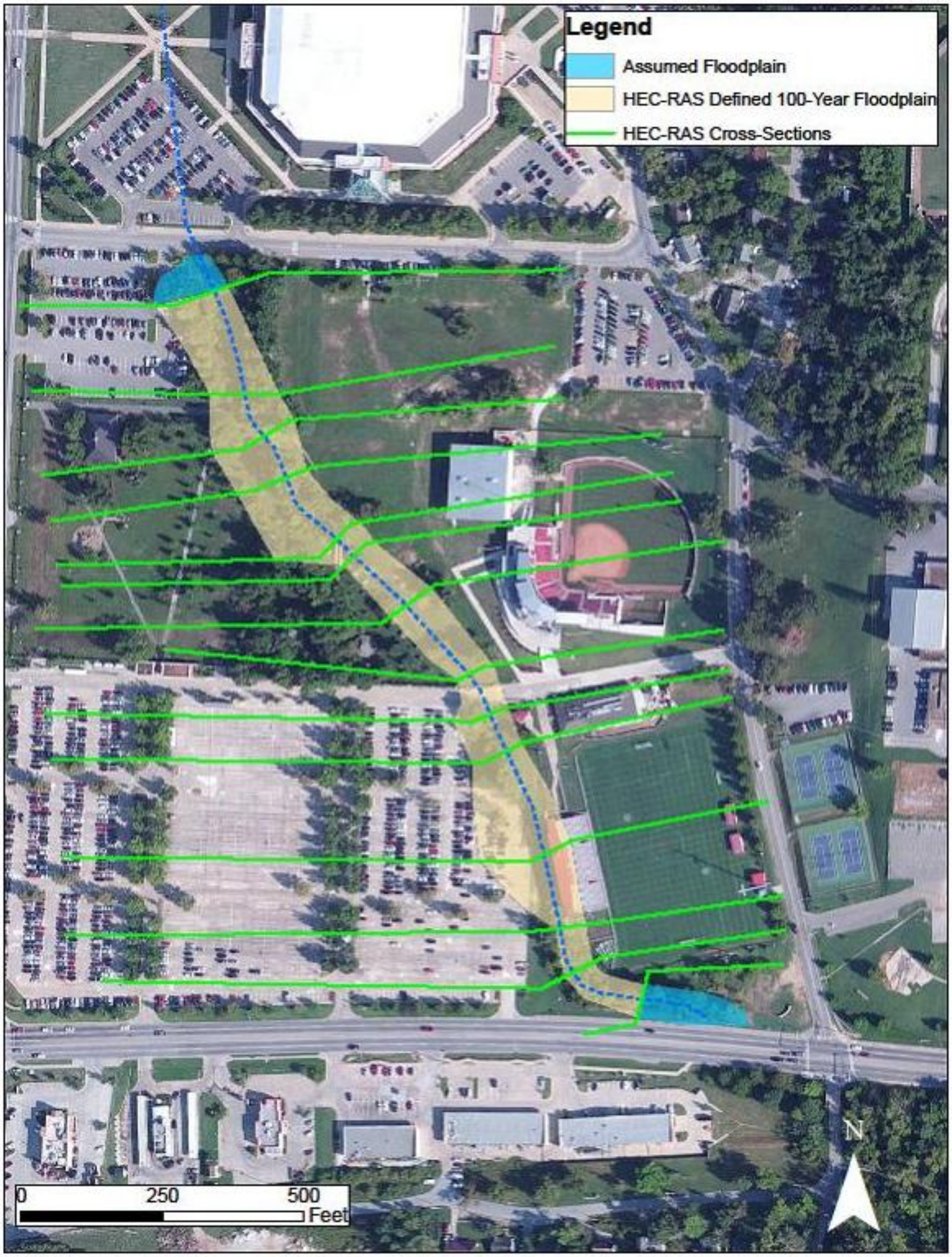

Figure S1. 100-Year Flood Boundary for Existing Conditions

Figure S2. 100-Year Flood Boundary for Two-Stage Channel Design Conditions

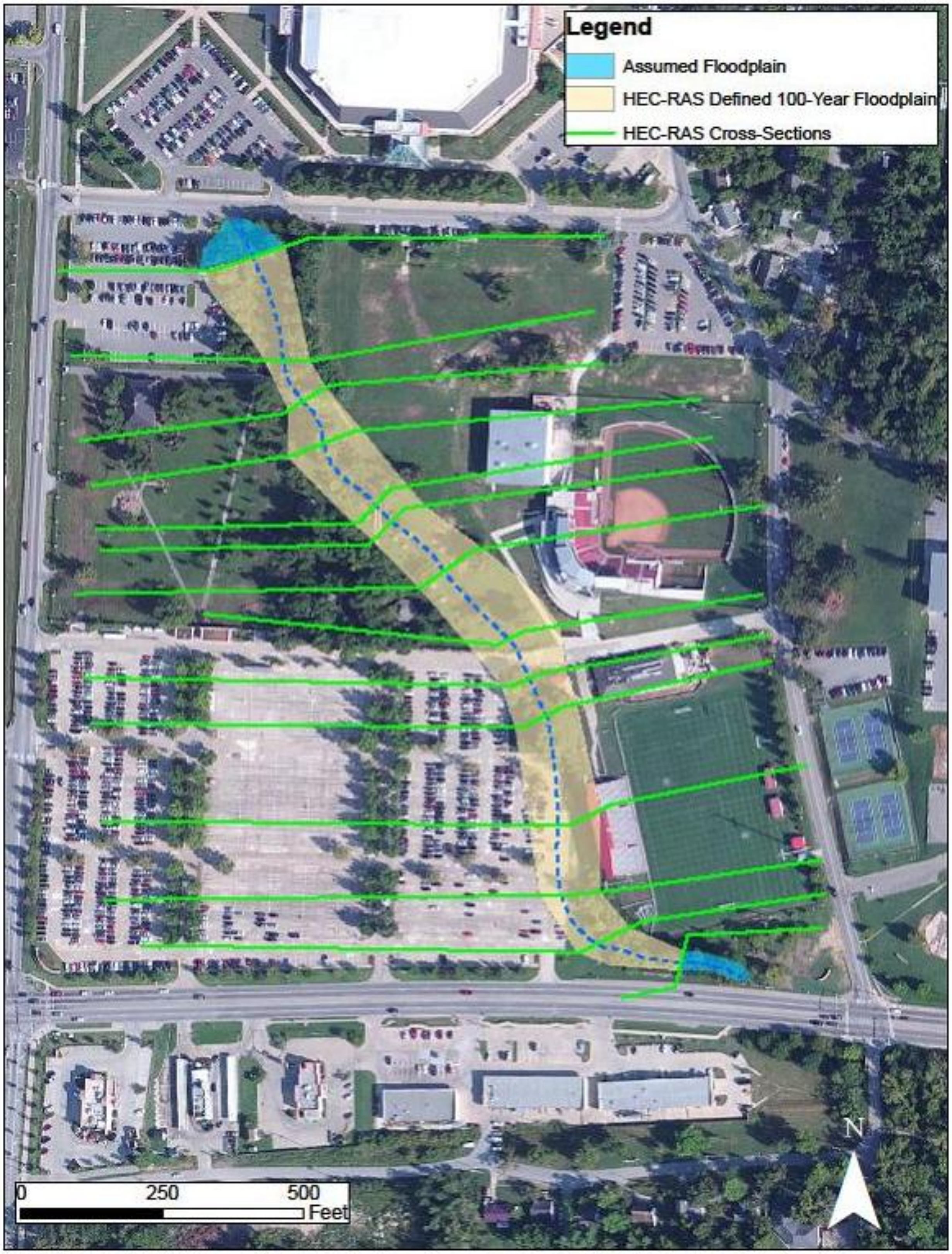

Figure S3. 100-Year Flood Boundary for Two-Stage Channel and Storage Design Conditions